ASSESSMENT OF BY-PRODUCT EXCHANGE POTENTIAL FOR INDUSTRIAL SYMBIOSIS IN ISLAMABAD

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A thesis submitted to the Department of Environmental Science, Faculty of Basic and Applied Sciences in partial fulfillment of the requirements for the award of degree of Doctor of Philosophy of International Islamic University, Islamabad.

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بِسْمِ اللهِ الرَّحْمٰنِ الرَّحِيْمِ

IN THE NAME OF ALLAH,
THE MOST GRACIOUS AND
THE MERCIFUL

DEDICATION

I dedicate this effort to my loving husband, parents, family, friends and respectable teachers, who believe in me sometimes more than I believe in myself.

DECLARATION

I *Nadia Akhtar*, PhD candidate in the Department of Environmental Science enrolled under registration No. 06-FBAS/PHDES/F13, hereby declare that the knowledge contributed by analyses of data collected and results derived to draw conclusion presented in this thesis titled "*Assessment of by-product exchange potential for industrial symbiosis in Islamabad*" is my own original work and has not been submitted as research work or thesis in any form in any other university or institute in Pakistan or abroad for the award of any degree. However, one research article from this research thesis has already been published in volume 17 (1) of *Applied Ecology and Environmental Research* indexed in JCR 2019 and couple of more are in the review process.

Dated: 25-08-2020

Deponent
Nadia Akhtar

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AGR	Agricultural Growth Rate
AFD	Air Filter Dust
CMI	Census for Manufacturing Industries
CPEC	China Pakistan Economic Corridor
DAIs	Degree Awarding Institutions
DFIs	Direct Foreign Investment
EAF	Electric Arc Furnace
EID	Eco-industrial Development
EIP	Eco-industrial Park
GDP	Gross Domestic Product
GGR	GDP Growth Rate
GHG	Greenhouse Gases
GIS	Geographic Information System
GWP	Global Warming Potential
ICCI	Islamabad Chamber of Commerce and Industries
ICT	Islamabad Capital Territory
IE	Industrial Ecology
IMF	Integrated Melting Furnace
IPCC	Intergovernmental Panel on Climate Change
IS	Industrial Symbiosis
ISO	International Organization for Standardization
JIE	Journal of Industrial Ecology
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MGR	Manufacturing Growth Rate
NCPC	National Cleaner Production Center
NEQS	National Environmental Quality Standards
NIES	National Institute of Environmental Studies
NISP	National Industrial Symbiosis Program

OBOR	One Belt One Road
Pak-EPA	Pakistan Environmental Protection Agency
PSIC	Pakistan Standard Industrial Code
SDGs	Sustainable Development Goals
SGR	Services Growth Rate
SMEs	Small and Medium Size Enterprises
SOP	Standard Operating Procedure
SWOT	Strengths, Weakness, Opportunities, Threats
UK	United Kingdom
UNEP	United Nation Environment Program
UNIDO	United Nation Industrial Development Organization
USA	United States of America
WBCSD	World Business Council for Sustainable Development

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First and foremost, praise and thanks to Allah, the Almighty for the countless blessings throughout my life and during this research work to complete the research successfully.

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Nadia Akhtar

ABSTRACT

The consequential impacts of anthropogenic interventions in the natural environment necessitate an integrated response. Thus, the conceptual framework of industrial symbiosis (IS) is gaining recognition in the context of circular economy (CE) to ensure conservation of natural resources, efficiency in the system and resilience in socio-ecological surroundings. The conceptual contours of IS are embedded in the philosophy of mutualistic benefits through the integration of interests. Significant scholastic strides have been made for explaining the conceptual paradigm of IS. In pursuance of these efforts, the current study, first used the bibliometric mapping technique to decipher the contemporary orientations in the literature published for a period (2012-2017) on industrial symbiosis. The findings revealed that China, UK and the USA are the pivot for promoting research interests in this field. The loci of research on industrial symbiosis were observed more skewed in favour of economically developed and industrialized countries. The results also found a growing propensity towards research collaborations between and among nations. The ensuing developments associated with the China Pakistan Economic Corridor (CPEC) are unfolding new prospects for Pakistan. Pakistan can serve as a hub and corridor of trade due to its geo-strategic location. Besides this, manufacturing activities are on the rise in Pakistan and likely to accelerate under CPEC regime. In this scenario, the strategies associated with the eco-industrial development (EID) offer viable options to cultivate economic benefits without compromising over the integrity of natural environment. Therefore, ensuing opportunities for industrial and economic progress nesscitates a thorough examination of the potential and prospect of EID in Pakistan. Thus, a concerted effort is required from stakeholders for EID for which baseline assessments regarding existing resource synergies are vitally required, but in short supply. This pilot study has been carried out with the aim to unearth existing and potential synergies in the industrial area of Islamabad. The study was designed to assess the benefits of such synergistic collaborations for the iron and steel industry and associated partners. The study tried to identify barriers and barricades on the way to increasing business partnerships and synergies along with a SWOT analysis to assess strengths, weaknesses, opportunitites and threats for eco-industrial development in context of Pakistan. Findings revealed that there are many key strengths to support the development of EID in the industrial area of Islamabad that may be scaled up in other industrial states in Pakistan. However, the loosely defined mechanism between the partners, the role of middle man and lack of information about the byproducts are the visible barriers for the synergistic collaboration. The scenario demands synchronized efforts for the health and resilience of human and natural resources. It is hoped that this study will not only initiate further studies of similar nature but also will be useful as pilot study in planning and designing for eco-industrial parks in the Special Economic Zones (SEZs) under China Pakistan Economic Corridor regime.

CHAPTER I

INTRODUCTION

CHAPTER-1

INTRODUCTION

1.0 General

Human activities extract, process and relocate substances and materials from the earth. The associated inputs, processes and outputs are obligatory for human survival and progression. However, such redundant materials as generated by manufacturing and industrial activities are exerting pressure on the natural and social environments through wastage of resources. These planned and unplanned anthropocentric intrusions for resource exploitation symptomatically define the contours of socio-ecological resilience. Industrial activities and its concomitant processes significantly augment the speed, scale and magnitude of such interferences in the natural environment. The phenomena of industrialization are also accountable for contemporary consumer-oriented life style. Thereby, the industrial activities and concomitant lifestyle changes are simultaneously depleting the natural resources and polluting the environment. The repercussions are proving stressful for the socio-ecological balance. The scenario demands for out of the box measures to protect the ecological, social and economic resources at all tiers of social existence.

1.1 Industrial symbiosis

In response to these socio-ecological obligations, the emerging approaches embedded in Industrial Ecology (IE), such as Industrial Symbiosis (IS), are gaining acceptance. The conceptual contours of IS are entrenched in the philosophy of mutualistic benefits. These benefits emerge from the integration of interests of various stakeholders (Chertow and Lombardi, 2005). Chertow (2007) elaborated the paradigm of IS by postulating a “3-2 heuristic minimum criterion”; at least three different entities must be involved in exchanging at least two different resources. These benchmarks turned out to be the catalysts that distinguished IS from other waste exchanges and resource sharing mechanisms. While, the most commonly used and referred classification (Van Beers, 2007)categorizes IS into three types i.e. by-product exchanges, utility/infrastructure sharing and joint provision of services These synergies and partnerships produce dividends in the form of enhanced economic gain (Chertow and Ehrenfeld, 2012) Therefore, this model is taking off as a potent tool for promoting symbiotic linkages among various ecological, social and economic components of environment for sustainable development (Dara et al., 1996; Thomas, 1997; Geng and Cote, 2002; Chiu and Yong, 2004a; Gibbs and Deutz, 2007; Hatefipour, 2012). .

Whereas, these orientations in the industrial activities are incumbent for the resilience of natural and social capital but the required focus towards such aspects is a missing link. This scenario is more alarming in the context of the developing regions of the world. The late start of industrial activities; lack of vision; inconsistencies and compromises over policies; paucity of technological and financial resources and less supportive environment for innovation are the plausible hurdles in the way to EID in these regions (Shenoy, 2016). However, the trickledown impacts of EID from the industrialized world, the effects of Direct Foreign Investments (DFIs) and growing concerns for the environmental degradation are imparting the needed stimulus for smart industrial production in these countries (Chiu and Yong, 2004a).

1.1.1. Importance of industrial symbiosis for Pakistan

Pakistan is striving to ensure sustainable industrial development for resilience of economy. For this purpose, different initiatives and industrial policies were experimented and deployed. The resultant expansion and growth in industrial sector has far-reaching implications for the transforming economy and natural environment of Pakistan. This penchant for industrial and manufacturing activities is likely to further accelerate under China Pakistan Economic Corridor (CPEC) regime. While, the lack of preparedness, capacity, financial constraints and resource limitations are the acknowledged impediments in the way towards eco-friendly industrial development in countries like Pakistan (Abid and Ashfaq, 2015). Therefore, the emerging scenario in the wake of CPEC, necessitates to examine the ensuing potentials and prospects for sustained EID in Pakistan. The synchronized and coordinated efforts from stakeholders are cardinal for achievement of desired objectives (Paquin et al., 2014) and its consequent benefits from CPEC.

1.1.2. Key challenges for symbiotic industrial development in Pakistan

In Pakistan, small and medium enterprises (SMEs) constitute approximately 90% of all industrial and manufacturing entities. These enterprises are providing job opportunities to 80% of the non-agricultural labor force. Besides this, they contribute 40% in the gross domestic product (GDP) of the country. However, these small enterprises are not in the focus of regulatory control. Besides this, these enterprises are mostly operating in the urban areas. Consequently, the employment opportunities in urban areas are stimulating rural to urban migration. The absence of reliable data curtails our knowledge of the kind and quantity of the waste generated by these SMEs. The empirical findings construe that there are significant potentials for resource recovery through these units such as revenue generation through 'salvages' in Pakistan. The lack of orientation and the consequent neglect from the stakeholders is the observable bottleneck towards the utilization of such avenues.

1.2 Statement of problem

It has become indispensable to regulate urban and industrial expansions without compromising urban environmental resilience. The unplanned and unregulated processes of urbanization and industrialization are encouraging “pollute now – clean up later” approaches, which has become a barrier for sustainable industrial development in Pakistan.

1.3 Rationale

The evolving scenario demands corrective measures and regulatory control. In this connection, the paradigm of IE and associated mechanisms embedded in the EID offer doable measures to attain the desired objectives. These initiatives are incumbent for ensuring cleaner production and conservation of resources for a more resilient environment (SWITCH-Asia, 2013). Regrettably, the domains such as IE and EID fail to attract the attention of policy makers, planners and researchers in Pakistan.

Therefore, keeping in view the realities stated above, the present study “Assessment of By-product Exchange Potential for Industrial Symbiosis Development in Islamabad” was designed, as a model project to be replicated in other parts of the country. The study evaluates and quantifies environmental and economic gains arising from utilization of industrial waste in SMEs, located in Islamabad (Pakistan). The study also identifies the barriers towards synergistic collaborations in industrial sector of this region. Besides this, the study will provide the baseline data for promoting eco-industrial development in Pakistan. The study will also contribute towards overcoming the knowledge gap regarding EID in developing countries.

1.4 Research questions

This pilot study attempted to answer following four research questions by interpreting data obtained from SMEs located in Islamabad keeping in view its scalability at country level.

1) How do the existing conditions support or challenge IS development in Pakistan?

2) To what extent information about supply and demand potential can facilitate IS?

3) Whether geographic information systems (GIS) be used to facilitate IS?

4) Whether environmental benefits of IS can be compared to systems where companies work independently?

1.5 Aim and objectives

The overarching aim of this study was to provide research-based input for planning eco-industrial development and circular economy in Pakistan. Whereas, specific objective was to develop a model industrial symbiosis framework for SMEs in Islamabad as pilot to be scaled up in larger industrial states. For achieving these objectives, following tasks were carried out:

1) situation analysis regarding industrial symbiosis in terms of its prospects and possibilities in Islamabad in particular and Pakistan in general;

2) identification, categorization, characterization of materials for defining various dimensions of industrial symbiosis;

3) use of geographic information system to facilitate industrial symbiosis; and

4) assessment of environmental performance of potential synergies in the industrial sector.

1.6 Organization of the thesis

The selected parameters in the objectives of the current study have been analyzed and discussed in the subsequent sporadic, yet interlinked chapters.

Chapter 2 deals with the contemporary research orientations in the field of industrial symbiosis. This chapter elaborates prevailing inclinations of contemporary literature regarding IS published during 2012-2017.

Chapter 3 gives methodological framework for systematic literature review as well as the approaches adopted to achieve research objectives.

Chapter 4 deals with the prospects of eco-industrial development in Pakistan. This part of the research addresses first objective of the study that focuses on the strengths, weaknesses, opportunities and threats for EID, including the role and contributions of stakeholders' i.e. government, academia and industry.

Chapter 5 unearths the byproduct exchange synergies among the SMEs in industrial area of Islamabad. This section deals with the identification, characterization and categorization of byproduct exchange synergies. It also attempts to provide geospatial mapping of potential producers and consumers.

Chapter 6 divulges on actors and evaluates the environmental and economic dividends arising from the identified byproduct exchanges in iron and steel industries.

Chapter 7 gives the conclusion of the study and provides directions for future research.

CHAPTER 02

CONTEMPORARY RESEARCH TRENDS

The output of synthesis of review of literature has been published in *Applied Ecology and Environmental Research* **17**(1):1159-1221 (2019)

titled as

"*A BIBLIOMETRIC ANALYSIS OF CONTEMPORARY RESEARCH REGARDING INDUSTRIAL SYMBIOSIS: A PATH TOWARDS URBAN ENVIRONMENTAL RESILIENCE*"

(APPENDIX. VIII)

CHAPTER-2

CONTEMPORARY RESEARCH TRENDS

2.1. Introduction

2.1.1. Industrial Symbiosis: Definitions, characterization and categorization

Industrial symbiosis (IS) initially emerged as a branch of the industrial ecology (IE). The most quoted definition is given by (Chertow, 2000) which defines IS as "engaging traditionally several separate firms and industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products". This concept of IS considers "collaboration", as synergic possibilities offered by geographic proximity", and "co-located firms" (Chertow, 2000; Jacobsen, 2006). Lifset and Graedel (2002) broadened the scope of IS by considering exchanges of IS within the firms or industries. A recent interpretation (Laybourn and Lombardi, 2012; Lombardi and Laybourn, 2012; Lombardi et al., 2012a) divulges that the theoretical framework of IS is based on engaging diverse production activities, through an integrated network in order to foster eco-innovation and long term cultural changes.

This emerging branch of knowledge tries to elaborate the interconnectedness of natural environment and human society (Chertow, 2008). Therefore, an understanding regarding mutualistic relationships among organisms help to re-design the process of industrial production for the sustainability of natural resources (Desrochers, 2001; Zhang et al., 2015a). The conceptual framework is gaining acceptance as a pragmatic strategy to improve efficiency in production activities (Laybourn and Lombardi, 2012). These strategies are obligatory and incumbent for ensuring the conservation of natural resources and achieving the goals of social, economic and environmental sustainability. The paradigm of IS envisaged a framework to engage traditionally disparate industrial activities in a synchronized manner for maximizing advantages. Thus, it emphasizes on physical exchange of materials, energy, water and byproducts through integrated linkages (Chertow, 2000). The traditional modus operandi in this regard was through collaboration and exploring the synergistic possibilities that transpire through preconceived integrations in a limited geographic proximity. However, with the advancements in theory and practice, the scope of IS now transcends the limitations of physical proximity (Laybourn and Lombardi, 2012).

2.1.2. Evolution of industrial symbiosis

Significant scholastic efforts have been made for explaining the concept of IS, defining its boundaries, its evolution, progression, practices and different strategies adopted to implement it during the last two decades (Chertow, 2000; Mirata and Pearce, 2006; Baas, 2011; Martin and Eklund, 2011; Laybourn and Lombardi, 2012; Lombardi et al., 2012b; MacLachlan, 2013; Marinos-Kouris and Mourtsiadis, 2013; Alfaro and Miller, 2014; Chertow and Park, 2016; Mauthoor, 2017). During this period, the focus of IS research witnessed a number of evolutionary transformations. Chertow and Park (2016) substantiated that the conceptual frameworks of inquiry in IS are changing in response to socio-economic and technological changes. They also perceived that such propensities are quite evident in case studies, mechanism adopted for investigations, proposals designed for investigations and modelling techniques relied upon for analysis in IS studies.

In this connection, Paquin and Howard-Grenville (2013) pronounced another aspect of such evolutionary tendencies and termed it a shift from “blind dates” to “arranged marriages”. Elaborating on this, they maintained that many of contemporary developments in the domain of IS research are now being facilitated by either governmental or non-governmental factors. The growing research inclinations in China towards IS are often cited to corroborate such assertions. In this country, the availability of large networks of eco-industrial parks (EIP) facilitated by the China National Demonstration Eco-Industrial Park Program are encouraging scientific publications in the field of IS. The other notable initiatives of similar objectives are National Industrial Symbiosis Program (NISP) in the United Kingdom (UK) and Resource Efficiency Flagship Initiative in Europe (Laybourn and Lombardi, 2012; Paquin and Howard-Grenville, 2013).

Despite increasing importance and interest in IS, focus on recalling earlier advances in the domain appeared a less explored arena of research. Two important papers authored by Yu et al. (2014) and Chertow and Park (2016) attempted to comprehensively review the orientations of research in this domain. The former group tried to quantitatively map and mention the noticeable strides in this domain from 1997 to 2012, while, the latter focused on the time period from 1997 to 2014. These researchers not only identified the seminal articles but also identified key themes, researchers and journals in this branch of knowledge. These researchers concluded that the field of IS stemmed from and was rooted in IE. Yu et al. (2014) identified five distinctive topical areas in the contemporary IS research i.e. wastewater treatment and management, solid waste management, energy efficiency, self-organization of IS systems, and policy making and evaluation of IS and EIP projects.Chertow and Park (2016) sub-divided their assertions into seven categories based on the nature of study: foundation, performance, mechanism, modeling, structure, case study, and proposal. Yu et al. (2014), divided the evolution of industrial symbiosis in to following two periods:

2.1.2.1. Research themes in 1997-2005

During this period IS appeared closely connected to IE, supply chain management, life cycle assessment, material flow analysis, exergy and energy. In initial years scholars looked for input from IE at large to describe observations regarding industrial linkages till publication of research article by Chertow (2000), who defined the conceptual contours, scope and boundaries of IS. Other researchers during this period dealt with practical EIPs, principle of IE and IS, and sustainable development aspects.

2.1.2.2. Research themes in 2005-2012

During this period, IS appeared to be connected with more diverse research themes. Connections of IS with theories from social sciences like regional economy and economic geography became more pronounced. As a result, role of co-location in IS development, role of EIPs in regional development, and policy instruments to stimulate synergies became more prominent features of research. More cases of IS were explored and reported during this period, including Austrailian Mineral Industry (Van Beers et al., 2007), Eco-industrial Parks of Ulsan, Korea (Park and Won, 2008), China (Geng and Hengxin, 2009; Shi et al., 2010), Japan (Ohnishi et al., 2012) and UK (Paquin and Howard-Grenville, 2013).

However, both of these studies deployed bibliometric analysis technique for assessments. The bibliometric or scientometric mapping (Cobo et al., 2011) approach is a visual technique of informatics. This assessment approach quantitatively displays structural and dynamic aspects of scientific research proclivities for the specified temporal duration (Liu and Gui, 2016). The technique also offers replicable opportunities for quantitative estimations and visual mapping in the domain of ecology (Neff and Corley, 2009; Govindaradjou and John, 2014). These features enable understanding the noticeable progressions in the field of interest for systematic review and assessments. It empowers the researchers to decipher the impacts of inter-disciplinary imprints on the prevailing mode of investigations. The bibliometric analysis is also considered helpful for postulating the emerging trajectories in research orientations (Yu et al., 2014). The similar nature of methodologies have been relied upon for analyzing evolutionary developments and contemporary advances in diversified fields of knowledge (Eito-Brun and Rodríguez, 2016; Liu and Gui, 2016; Mishra et al., 2016; Atif et al., 2018b).

2.2. Material and methods

The bibliometric or scientometric mapping technique relied upon deciphering the contemporary research orientations in the domain of IS. Presnet study deployed co-occurrence analysis technique to identify networks of collaborating organizations, countries, citations and co-authorships. The technique facilitates the representation of the related items with the help of network maps through nodes and links (Liu and Gui, 2016). The size of the node is a measure of centrality and thus depicts the importance of the impacts (Wasserman and Faust, 1994). The larger nodes served as hubs in the analysis thereby depicting the significance of articles, keywords, and authors.

The technique is considered reliable (Yu et al., 2014) and was deployed to analyse the spatio-temporal trends and to identify intellectual communities engaged with research concerning IS. It was subsequently relied upon for the "keyword co-occurrence analysis test" to understand the emerging developments in the domain of IS studies. Table 2.1 succinctly describes the nature and scope of study, data sources and the methodology implemented for data retrieval and assessments of facts.

2.2.1. Data collection and preparation

Present study is a meta-analysis, based upon the bibliographic information, retrieved from Scopus. The study focused on the research published between January 2012 till March 2017 against the search term "industrial symbiosis". Ostensibly, it seems that the use of a single keyword may compromise the authenticity of findings by excluding the related studies with different nomenclatures but at the same time avoiding digressions. Atif et al. (2018b) has successfully experimented this technique, where the query returned 398 records, which were further scrutinized for relevance, thereby selecting 395 records (Appendix-I) for further processing. The data was refined using Notepad ++ to standardize the variants used in keywords, authors, journals, organizations and country names.

Table 2.1. Study approach adopted for exploring research productivity trends in IS (2012-17)

Objectives	**Questions**	**Indicators**
Spatio-temporal distribution of IS research productivity	How many documents are published annually?	Number of documents published per year
	Which are the most productive countries?	Number of publications per country
	Key institutions involved in IS research	Ranking of key organizations and collaboration network
Identify most productive research communities	Who are the most productive authors?	Ranking of most productive authors by complete count method
	Who are the authors that collaborate?	Co-authorship Analysis
	Who are authors that share a common interest?	Co-citation analysis
Key lines of research	Which are the key subject areas under which IS research is being carried out?	Contribution by subject based on Scopus classification
	What are the key themes of IS research?	Keyword Co-occurrences

2.3. Results

Since the study aims, primarily, to cover all aspects of research concerning IS for 2012 - 2017 period, therefore documents from all countries and languages available have been thoroughly scrutinized. For this purpose 395 publications, specifically related to “industrial symbiosis” were retrieved from the Scopus database for the selected time interval. These studies were carried out by the authors from 24 countries related with 20 different disciplinary areas. The data retrieved included: articles (262), other documents included conference papers (59), book chapters (28), articles in press (22), review articles (15), conference reviews (4), books (2), editorials (2) and the solitary available note. These articles were published in three languages: English (383), Chinese (10) and German (2).

In this connection, the following top five journals i.e. Journal of Cleaner Production (92), Journal of Industrial Ecology (JIE) (43), Resources, Conservation and Recycling (13), Computer Aided Chemical Engineering (11) and Shentai Xuebo Acta Ecologica Sinica (11) were observed in the forefront, whichaccount for 42.7% of the total published documents.

2.3.1. Spatio-temporal distribution of research

The spatio-temporal connotations of these scholastic linkages were also magnified with the help of distribution maps and statistical diagrams. The approach is considered helpful for depicting the scholastic collaborations between and among nations (Liu and Gui, 2016). The topic of IS appeared in literature around 1997, afterward, it grew exponentially with correlation coefficient $r^2 = 0.88$ (Figure 2.1). The findings in Figure 2.1 also depicting the research productivity of the previous five years (2012-17) in relation to overall research published since 1997.

Spatial scope of IS has expanded to 24 countries (Figure 2.2) during this period and research hubs are mainly located in industrialized contextual settings (Appendix-II) such as China (85), United Kingdom (49) and United States (49). The other countries with significant contributions are Italy (34), Japan (27), Netherlands (21), Philipines (21), Australia (19), Canada (19), and France (19). The findings revealed that 363 organizations from these countries are involved in IS research. In this connection De-La-Salle University, Manila (22), National Institute for Environmental Studies (NIES) for Japan (21), University of Surrey, United Kingdom (19), University of Tokyo, Japan (11), Tsinghua University, China (11) and the University of Nottingham, Malaysia (11) are the most prominent contributors towards IS research.

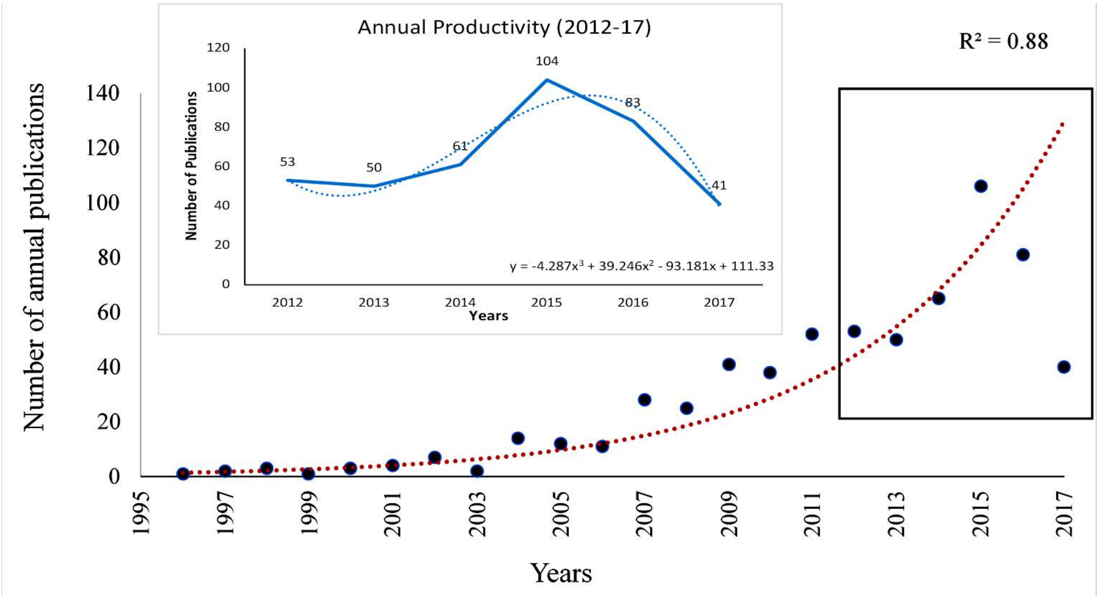


Figure 2.1. Annual productivity in IS research (1997-2017). Inset shows recent fluctuations encompassing during 2012-17

The subsequent co-occurrence frequency analysis depicted a growing tendency towards collaboration between and among different nations. In this regard, the highest scientific collaboration was observed between China and Japan in 17 cases. The participating organizations in these collaborations are the Chinese Academy of Sciences, the NIES, Japan, and Nagoya University, Japan. Liang Dong, Tsuyoshi Fujita (affliated with NIES, Japan) and Yong Geng (chief researcher, Chinese Academy of Sciences) are, apparently, the most active contributors in this network. Most of these scientific research collaborations in were funded through various programs of Natural Science Foundation of China (11) and Ministry of Environment of Japan (8).

2.3.2. Research communities

The current study also attempted to identify the most productive authors with respect to a number of publications produced during 2012-2017. The ranking is based on the complete count method. In this scheme of assessments every occurrence of the author is counted, provided his name has been mentioned in the list of co-authors in a publication selected for this study. Total citations and h-index were subsequently calculated using the Bibexcel and presented in Figure 2.3.

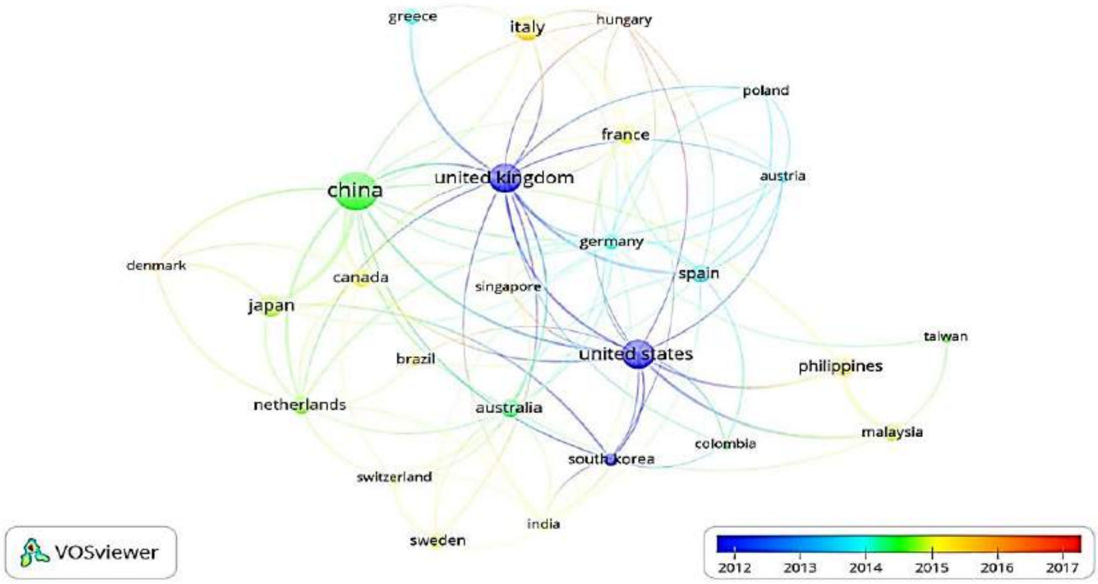


Figure 2.2. Geographical network of IS research productivity retrieved from corresponding author addresses (2012-17).

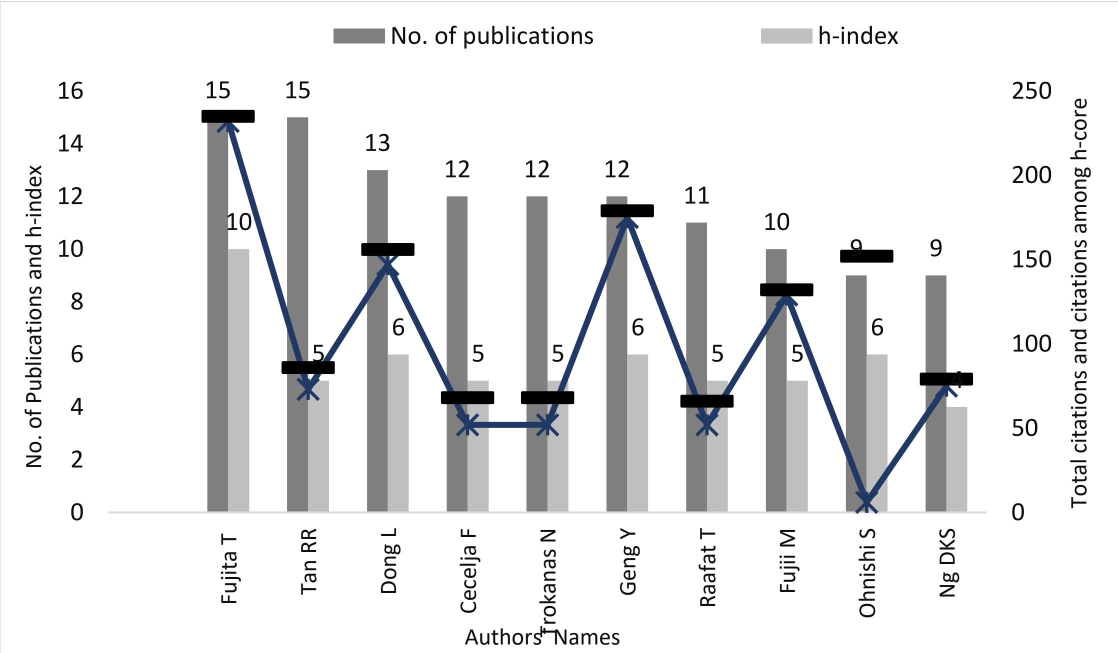


Figure 2.3. Ten most productive authors based on number of publications and h-index (N=395).

Tsuyoshi Fujita from NIES, Japan and Raymond R. Tan from De La Salle University, Philippines, were two most proficient and productive authors with 15 publications each. It is pertinent to mention that NIES, Japan, (20) and De La Salle University (33) emerged as the most productive organizations. However, scientific contributions by T. Fujita has received more acknowledgments in terms of citations (235) than R. R. Tan (86).

2.3.3. Clusters in research collaborations

The selected publications were analyzed to find out the scale and orientation of contemporary research collaborations. To identify the most productive collaborating authors, a co-authorship network map was developed using VOS viewer (Figure 2.4). The findings have been condensed in Table 2.2. The findings in the table convey the affiliations of authors, the focus of research and published studies ensuing from these research collaborations.

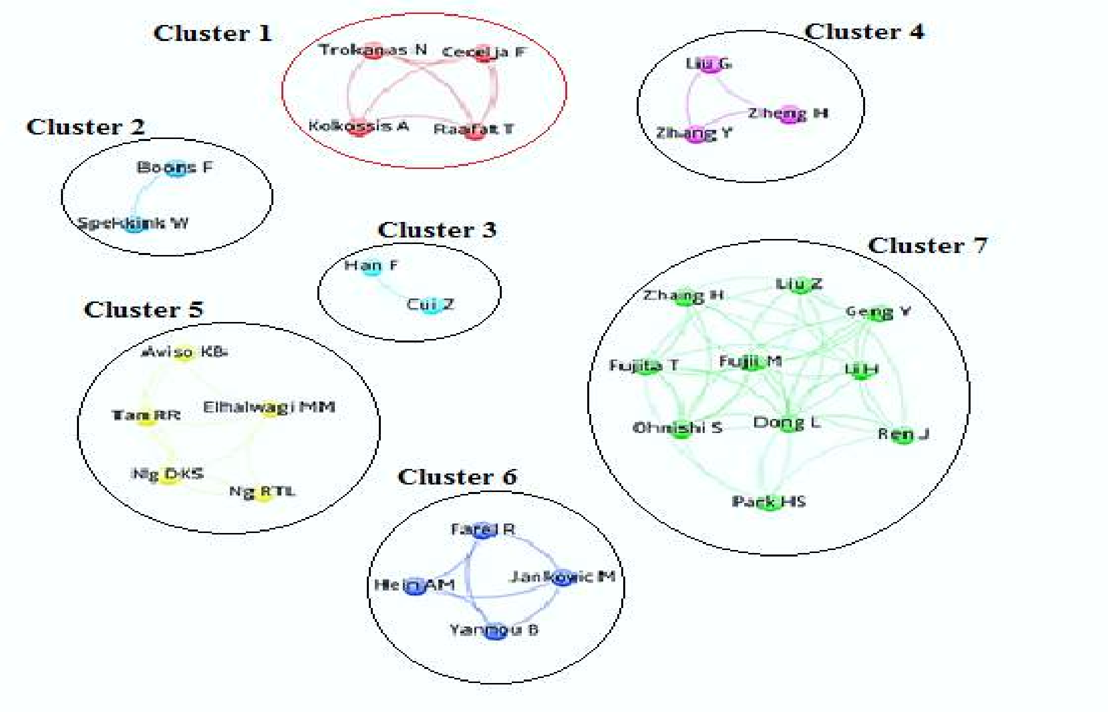


Figure 2.4. Clusters of co-authorship network working on IS

2.3.4. Co-citation analysis

Co-citation analysis technique is also relied upon to understand the conceptual orientations and imprints of contemporary research. The findings of current study in (Figure 2.5) portrayed that Marian Chertow, Yong Geng and Raymond Tan have the appreciable bearings and followings in the domain of IS research.

Table 2.2: Co-authorship cluster classification with affiliations and research areas

Cluster Number	Scholars Affiliation	Research Area	Reference Literature
Cluster 1	-Center for Process and Information Science, -Faculty of Engineering and Physical Science, University of Surrey, UK -National Technical University, Athens, Greece	Semantic and ontological approaches for IS	(Trokanas et al., 2012; Trokanas et al., 2014b; Trokanas et al., 2014a; Trokanas et al., 2014c; Trokanas et al., 2015a; Trokanas et al., 2015b)
Cluster 2	-Sustainable Consumption Institute, University of Manchester, UK -University de los Andes, Bogota, Columbia	IS dynamics and influence of different factors	(Boons et al., 2011; Boons and Spekkink, 2012; Boons et al., 2014; Boons et al., 2015; Boons et al., 2017)
Cluster 3	-School of Environmental Science and Engineering, Shandong University, China	IS application in China	(Yu et al., 2015b; Yu et al., 2015c; Yu et al., 2015a)
Cluster 4	-State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, China	Network analysis of IS Systems	(Zhang et al., 2013a; Zhang et al., 2013b; Zhang et al., 2013c; Zhang et al., 2015a; Zhang et al., 2015b; Zhang et al., 2015c; Zhang et al., 2016)
Cluster 5	-Center for Engineering andSustainable Development Research, De La Salle University, Manila, Philippines. -Department of Chemical and Environmental Engineering, Centre of Excellence for Green Technologies, University of Nottingham, Malaysia Campus. -Department of Chemical and Biological Engineering, University of Wisconsin, United States of America	Fuzzy programming and optimization based IS system and EIP designs	(Ng et al., 2014a; Ng et al., 2014b; Ng et al., 2014c; Tan et al., 2016)
Cluster 6	-Laboratoire Genie Industriel, CentraleSupélec, Université Paris-Saclay, France, Paris-Saclay Energy Efficiency (PS2E), France	EIP design architecture and modelling for IS	(Hein et al., 2015a; Hein et al., 2015b; Hein et al., 2016; Hein et al., 2017a; Hein et al., 2017b)
Cluster 7	-National Institute for Environmental Studies, Japan. -National Engineering Laboratory for Hydrometallurgical Cleaner Production Technology, Institute of Process Engineering, Chinese Academy of Sciences, China.	Low carbon IS options, environmental and economic benefits of IS for China	(Geng et al., 2009b; Dong et al., 2013a; Zhang et al., 2013a; Zhang et al., 2013b; Zhang et al., 2013c; Zhang et al., 2015a; Zhang et al., 2015b; Zhang et al., 2015c; Zhang et al., 2016)

	-Center for Social and Environmental Systems Research, NIES, Japan -Centre for Engineering Operations Management, Department of Technology and Innovation, University of Southern Denmark. -School of Environmental Science and Engineering, Shanghai Jiao Tong University, China University of Ulsan, South Korea		

2.3.5. Keyword analysis

Keyword co-occurrence maps represent the cognitive structure of a discipline. Atif et al. (2018b) opined that the selection of keywords depicts the focus and orientation of the scientific research. For this purpose, the keywords from the publications were retrieved and processed for analysis. The findings have been illustrated in Figure 2.6. Only such terms as the ones recurring at least five times were mentioned. The strategy was deployed to overcome the excessive noise. Figure 2.6 displays an overlay visualization of the keyword co-occurrences. The size of the node reflects frequency, while, the color of the node represents the publishing time period.

The central nodes represent the keywords such as “industrial symbiosis” (277), “industrial ecology” (123), “sustainable development” (77), “industry” (76), and “eco-industrial park” (67),“waste management” (43), “environmental impacts” (42) “recycling” (41), “economics” (39), “Life cycle assessment” (33) and “carbon” (25) appeared in appreciable numbers in the analysis (Figure 2.6).

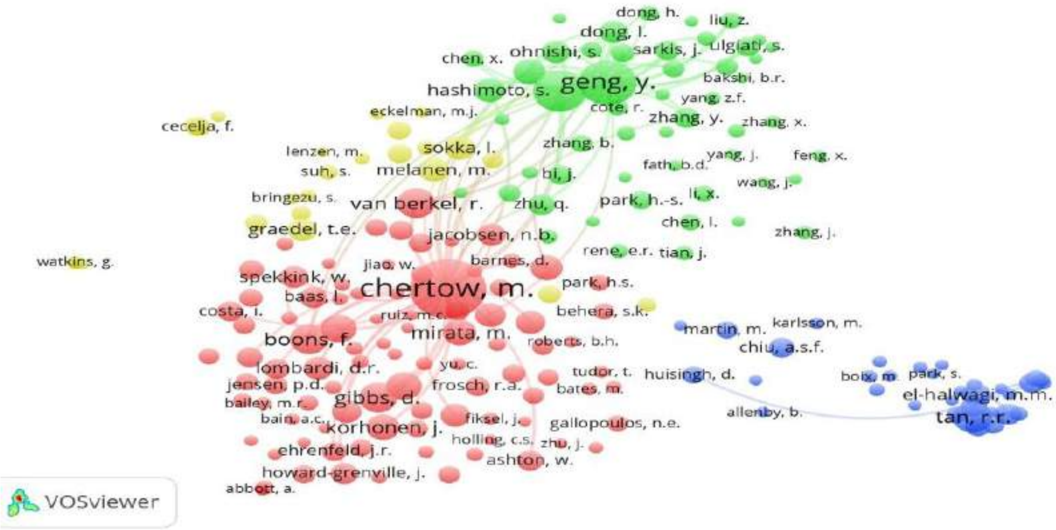


Figure 2.5. Co-citation network map of cited authors in documents retrieved from Scopus database

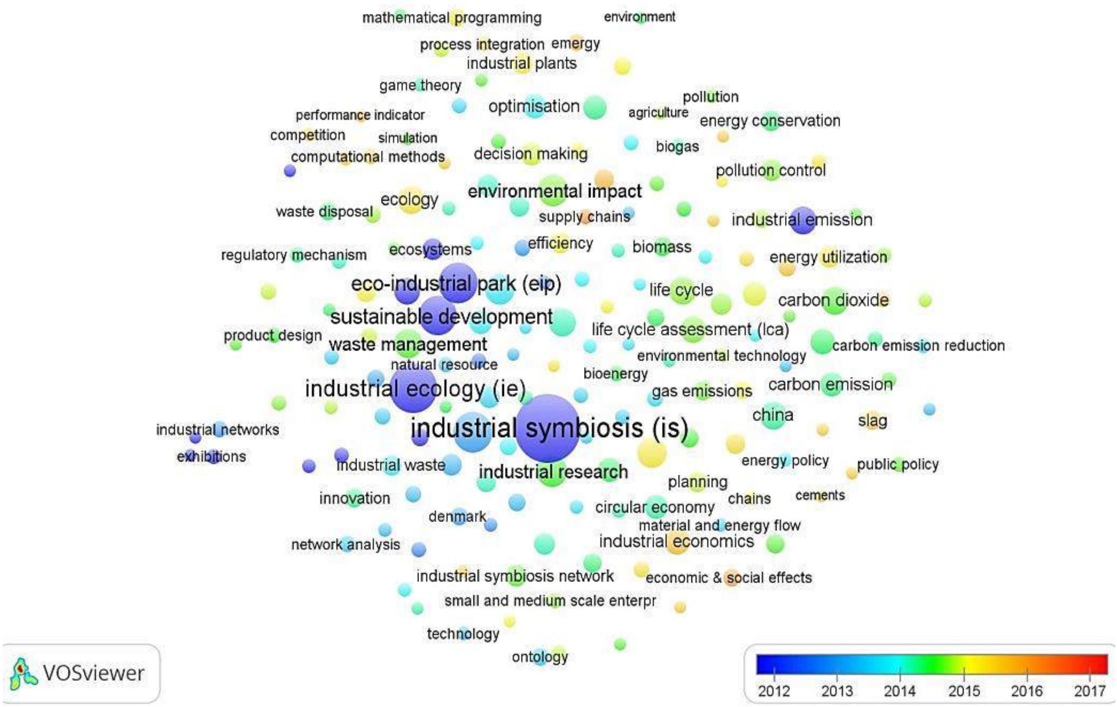


Figure 2.6. Keyword occurrences in IS related literature for 2012-17

2.4. Discussion

The resource depletion, accelerating demands for goods and services are compelling the human conscience to strive for environmental and ecological sustainability. The researchers and policy makers are striving to postulate doable measures to achieve these goals. Chertow (2000) proclaimed that in response to these demands the research inclinations towards IS started to gain acceptability from 1997 onwards. Figure 2.1 corroborate and substantiate these assertions. During the span of two decades (1997-2017), IS has evolved from a "signature topic" (Lifset, 2012) in IE to a more systematic, promising and advancing research discipline. As a result, the IS studies are gaining significant attention.

The findings of the study revealed that a large share (34%) of the publications were contributed by two journals, viz. Journal of Cleaner Production and Journal of Industrial Ecology (JIE).Similar findings were reported by Yu et al. (2014).

Figure 2.2 also pointed towards growing research collaborations between and among nations, ranging from regional to inter-continental engagements. These findings are in line with the assertions of previous investigations. In this connection, Chertow and Park (2016) and Yu et al. (2014) opined that IS is an advancing interdisciplinary field and rapidly attracting the attention of the research community. In this regard, China from Asia, UK from Europe and USA from the North America were identified as hubs and stimulators for promoting research interests in the field. The findings of present study also portrayed that the majority of collaborations are being carried out by developed industrial economies. While the orientation towards IS research was observed in fomenting stages in the Southern Hemisphere. However, a growing penchant for such cross-country collaborations was also noticed, e.g. India (7) is shifting from an agricultural to an industrial economic base.

The research collaborations are needed and encouraged (Iglič et al., 2017) for postulating pragmatic strategies to address the issues from divergent contextual settings. The findings based upon co-authorship analysis help to identify major research groups/collaborations in the field of IS. Figure 2.1 and Table 2.2 portrayed the emergence of seven distinctive streams of investigations as an outcome of these research collaborations. The most frequent research collaborations were observed among the researchers from China, Japan, Phillipines and UK. The most productive cluster (07) published (09) papers. This collaboration was observed among researcher from NIES, Japan, Chinese Academy of Sciences, China, University of Southern Denmark and University of Ulsan South Korea. This cluster is also the biggest in terms of number of researchers (10) engaged in collaboration.

The findings of present study (Figure 2.5) substantiate the previous assertions of Yu et al. (2014) that the scholastic contributions of Marian Chertow have more acknowledgment than any other scholar in the domain. The scholar is credited for defining the scope and sphere of this emerging research domain. In this context, Geng et al. (2009) and Tan et al. (2016) were observed as the next most influential scholars, having significant bearings on the emerging paradigm shifts in the field of IS.

The emerging dimensions of industrial symbiosis research were observed more focused on minimizing the impacts of industrial production on environmental, social and economic capitals. These initiatives are incumbent for ensuring the conservation of natural resources and the resilience of socio-ecological surroundings.

2.5. Conclusion

The field of IS is gaining acceptance for achieving objectives through integration of industrial production systems and collaborative research efforts. The current study revealed growing inclinations towards IS research. The findings portrayed that field is diversifying in scope and gaining acceptance from across the globe. The outcome of the study also depicted that industrial economies such as China, UK and USA are spearheading the domain of IS research. The plausible explanation for the growing orientations towards IS research in China can be the premise that the industrial growth remained steadier in this region. The research paradigm in IS is mainly conceived to ensure low carbon emission through research collaboration. The policy makers and researchers in China are stressing and promoting cross-country collaborations. More focused efforts will be required in the domain of IS to achieve the ultimate goal of clean and green industrial production in the face of mounting pressures from consumer-oriented life-style changes.

CHAPTER 03

RESEARCH METHODOLOGY

CHAPTER -3

RESEARCH METHODOLOGY

This chapter presents in a consolidated form, various methods used in this research work to address research questions framed to achieve aim and objectives. The aim of the present study was to provide research-based inputs for planning eco-industrial development for promoting circular economy in the country. For this purpose, a comprehensive logical framework of research was planned to address each research question, derived from assessments through literature review, inferences from a pilot survey and field observations, which helped to formulate an integrated research strategy. The research methodology deployed in this investigation helped to address research questions mentioned in Section 1.5 and objectives mentioned in Section 1.6 of Chapter 1. The methodical framework of this investigation inherently deals with four interlinked, yet, distinctive perspectives of the study. The division enabled us to have a systematic understanding of the phenomena and its ramifications for contextual setting in Pakistan. The detail of each method is presented in corresponding chapter or section.

3.1 Orientations towards industrial symbiosis

In order to decipher the orientations towards industrial symbiosis (IS) a systematic review and analysis of the scientific literature was carried out (Chapter 2). The detailed methodological framework adopted for analysis of literature is already provided in Section 2.2 (Chapter 2). For the purpose, the bibliometric or scientometric mapping technique was relied upon to decipher the contemporary research orientations in the domain of IS. Published literature was retrieved from Scopu database for 2012-2017 period. A total of 398 records were retrieved which were then refined for their relevance to IS, and 395 records were processed for quantitative analysis including spatio-temporal, co-citation, co-authorship mapping. For this purpose, BibExcel and VOS Viewer tools are used. Table 2.2 decribes in detail the analysis framework adopted for this systematic literature review.

3.2 Eco-industrial development (EID) and responses for environmental resilience

Chapter 4 of this dissertation deals with the prospects of EID in Pakistan. This part of the thesis particularly assesses the inclinations towards this emerging paradigm for ensuring environmental resilience in Pakistan.

The data was gathared from academic, industrial and state institutions on intitiatives that can act as barrier and enablers for eco-industrial development. Data gathered includes information on education and reasearch in tertiary level education, industrial initiatives, policies, programmes, regulatory framework from groverment at federal as well as provinical levels. For evaluating the role of the academia, an inventory of courses offered by degree awarding institutions (DAIs) was prepared through web survey of the programs offered by 167 DAIs in Pakistan. Besides, 140 curricula, revised by HEC between 2004 and 2017 were also adjudged for relevance to IE and, subsequently more thoroughly probed. Data on research contributions of the academia in EID was retrieved from the repository of Higher Education Commission (HEC) of Pakistan for furthur inferences and assessments (http://eprints.hec.gov.pk/ since 1990s). The review of relevant legal and policy documents was carried out. The primary motive of this exercise was to evaluate the initiatives for EID in Pakistan. In this connection, the relevant activities such as the industrial project reports, initiatives from industrial associations and governmental organizations were scrutinised to identify the factors that can contribute towards EID in Pakistan.

Besides this, consultative meetings with the stakeholders from academia, industries, and government sector, were held to explore the potential of EID in Pakistan. Output from stakeholder's meetings helped in identifying and grouping strength, weakness, opportuities and threats (SWOT) for EID in Pakistan.

3.3 Identification, characterization and classification of byproduct exchange synergies

The identification, characterization and classification of byproduct exchange synergies options were probed to support Industrial symbiosis in Pakistan. For this purpose, small and medium sized industries located in Islamabad Industrial Area were selected. The schematic representation in Figure 3.1 conclusively illustrates the assessment approach adopted for the purpose. The schematic diagram summarize the methodological procedures and measures relied upon for the analysis and assessments.

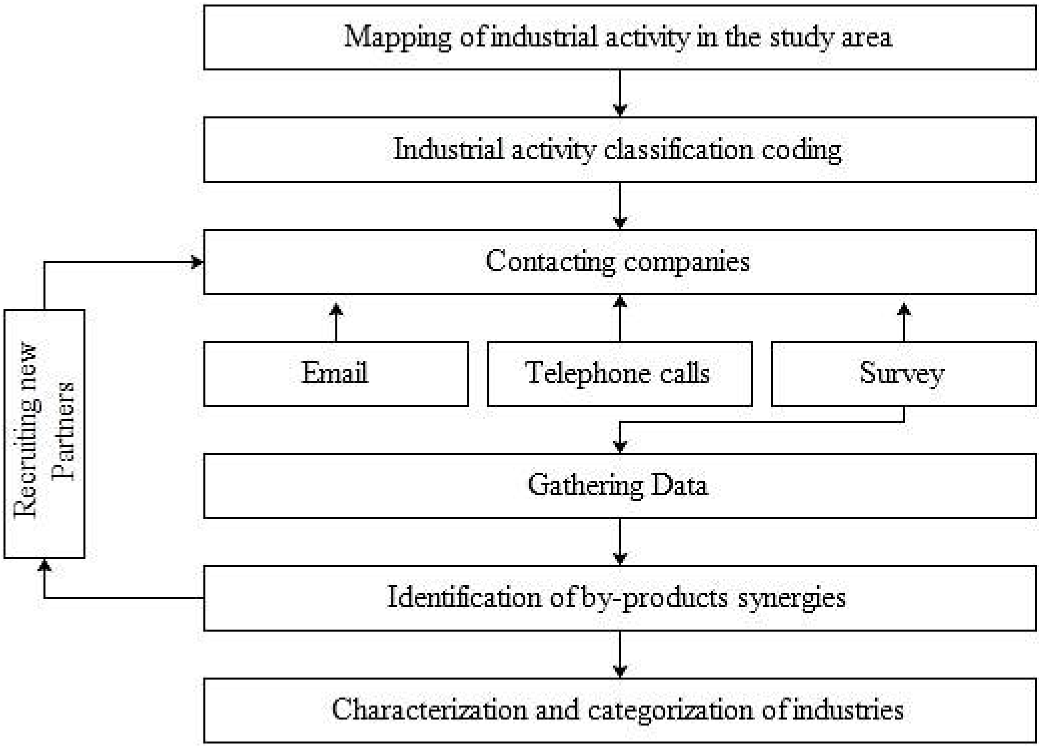


Figure 3.1: Schematic representation of methodology for assessments of by-product exchange potential

3.3.1 Study area

The study context is referred to as the Industrial Estate of Islamabad (IEI) which falls under the administrative jurisdiction of Islamabad Capital Territory. IEI was established in 1963, which is the home of about 117 industrial facilities of diverse nature. The industrial activities are primarily categorizing into three distinctive types; large scale industries, medium scale and small scale or cottage industries. The compartmentalization is made on the basis of investment or the workforce. The large scaled units engage a bigger labor force. The noticeable large scaled industries in this area are the steel manufacturing units, pharmaceutical industries and flour mills, each engaging 100 - 250 employees. The variation in the number of staff reflect the operational capacity of the unit.

The majority of the enterprises in the study area engaged smaller number of employees' (10 - 15. Therefore, the significant proportion of industrial activities are categorized as small and SMEs. The numerical strength of the workers in these industrial entities depends on the nature of processing and scale of production. The marble processing industries constitute the major proportion (17.9%) of such SMEs. These entities are the member of Islamabad Chamber of Commerce and Industries (ICCI) and are regulated by Pakistan Environmental Protection Agency (Pak-EPA). The Pak-EPA is mandated for the effluent's regulation and emission control. However, neither Pak-EPA nor ICCI) has a regulatory and monitoring control over these SMEs.

Resultantly, these enterprises keep on shifting their operations without a plan or strategy. The existing lacunas demands a pragmatic solution based upon the ground realities. Therefore, the preparation of an inclusive inventory pertaining to industrial units operating in the study area is needed. The inventory is also useful to plug the gapes in the standard operating procedures (SOPs) for regulatory supervision.

In the first step, a comprehensive list of industries, operating in the study area was prepared. For the purpose, information was obtained from ICCI and Pak-EPA. The list infer that 184 industrial units are operating in the study area. Subsequently, the list was scrutinized through field investigation. The field examination helped to ascertain the number of units operating at their designated locations. This information was ported in the Geographic Information System (GIS) for spatial/temporal assessments. The related details such as the nature of production, number of employees, contact details and certification status, etc. were also collected during these preliminary investigations.

This approach for field investigation was deployed due to following advantages:

1) It enabled to interact with the respondents in an informal way;

2) The approach provides an opportunity to dissect the ground realities and acquire updated information; and

3) The insights from the industrial partners helped to develop a conclusive survey booklet for the study.

3.3.2 Classification of the industrial activities

Pakistan Standards for Industrial Activity Code (PSIC) were formulated in 2010 (GoP, 2010). The document defined the manufacturing units as those establishments which are involved in the physical or chemical transformations of materials or substances into new product(s). The classification compartmentalizes the producing units into different classes and subclasses. This scheme focuses on the inputs, processes and technologies deployed for industrial and manufacturing productivities.

PSIC classification system is meant to encompass and reflect the industrial diversity of the country. Thus, the PSIC provides a viable framework to collect, process, analyze and report the data pertaining to industrial activities. The format is viewed as suitable for economic analysis, decision and policy-making (Ruiz-Puente et al., 2014). Therefore, the scheme was relied upon to classify the industrial activities of the study area. The results in the Table 3.1 concisely convey the codes used by the PSIC to define a specific industrial entity.

Table 3.1 The industrial activities in the Islamabad Industrial Area

PSIC Code	Industrial specie	Total units (#)	Units participated in the study ()	Main products
C-24	Manufacture of Basic Metal			
C-24104	Basic Iron and Steel	04	04	Still Billets
C-24106	Steel Structural Products	18	11	Iron Bars, T-Iron,
C-24108	Fabricated metal Products – Pipes	02	02	Galvanized iron pipes
C-25	Manufacture of Fabricated Metal Products			
C-25112	Fabricated metal products including aluminum	02	02	Aluminum Windows, stair case, doors
C-10	Manufacturing of Food Products			
C-10611	Grain processing mills-wheat	36	14	Flour
C-10612	Grain processing mill-rice	01	01	Polishing and finishing of Rice
C-10713	Baked food products	03	02	Bread, Rusk, Rolls
C-10796	Sauces and Spices	01	0	Ketchup
C-20	Chemical and Chemical Products			
C-20236	Cosmetics	01	0	Cosmetics and Toiletries
C-20232	Soap and detergents	05	0	Soaps
C-21	Basic Pharmaceutical Products & Pharmaceutical Preparations			
C-2100	Pharmaceutical Products	09	Excluded	Medicines
C-23	Manufacture of other non-metallic Mineral Products			
C-2396	Marble Processing	21	17	Marble tiles for wall and floors
C-22	Manufacture of Rubber and Plastics Products			
C-2219	Polymer Industries	01	01	Cooling system rubber parts
C-22202	PVC Pipes	05	04	PVC pipes
C-13	Manufacture of Textile			
C-13921	Woolen Mills	02	02	Knitted Caps, coats
C-27	Manufacture of Electrical Equipment			
C-2710	Electrical Motors and parts	01	0	Electrical Motors, solar panels, etc
C-29	Manufacture of Motor Vehicles, Trailers and Semi-trailers			
C-29301	Parts and accessories of motor vehicles	01	0	Trucks and Axle Parts
C-31	Manufacture of Furniture			
C-31001	Manufacturing of Wood Furniture	01	01	Sofa, beds, Chairs
C-26	Manufacture of Computer, electronics and optical products			
C-26302	Communication Equipment	02	0	RF Modules, Digital Signal Processing devices
	Services industry			
G-4520	Automobile workshops	01	01	Repair & maintenance of motor vehicles
H-49238	Logistics & Transport	02	0	Provide Freight transport

3.3.3. Contact with companies

A three-tier approach was adopted to contact the identified (108) industrial units. At the first level, the probable respondents were contacted through email (Appendix-V). Regrettably, a smaller number (4) responded. At the second level, telephonic contacts were made for the purpose. During these telephonic conversations, a brief introduction about the study was provided, with the intent to encourage their participation in the research project. As a result, 44 industries agreed to participate in the study. At the third level, those who were willing to participate in the study were visited. During these visits, a survey booklet (Appendix VI) was distributed for data collection. For gathering requisite information more than one visits were made. During these contacts, the liaison with 17 other similar entities were established, with the assistance of the initial respondents on the principles of 'snow balling' technique. These industries either have business contact with the selected industries or a synergistic partnership of a participating entity.

3.3.4. Data collection tool

A survey booklet was formulated as a tool for the data collection. The survey booklet comprises over four sections: i) general information about the industry, ii) input(s) used in the processing, iii) output(s) of the unit and the section, and iv) their synergistic collaborations (Appendix VI). The first part of the booklet was completed during the preliminary investigations. The second and third parts provide a list of the options regarding the probable inputs and outputs related to the industrial processing. These sections were specifically tailored to accommodate the prevailing diversity in the industrial activities of the study area. For the purpose, the consultation with ICCI and Pak-EPA proved informative. The fourth section was designed to decipher the level of awareness regarding IS. The data was subsequently analyzed to identify existing and potential synergies trends and options for action. The field survey for the present study was carried out during 2017 for which complete data was available.

3.3.5. Identification of synergies

The potential synergy prospects were identified with the help of literature review. In this connection, Heabi By-Product Synergy Project initiated by World Business Council for Sustainable Development (WBCSD) was consulted *(https://marketplacehub.org/item/hebei-by-product-synergy-project/)*. Besides this, the brainstorming sessions with industrial partners and members of ICCI were conducted to accommodate their perspectives about contextual possibilities and potentials. It is pertinent to mention that due to resource constraints, only by-product synergies collaborations within the study area were focused.

3.3.6. Characterization and categorization of synergies

Many researchers have attempted to characterize and categorize the synergistic collaborations in the industrial sector. The present study anglicized the criteria of spatial setting/ geographical location as proposed by Chertow (2000) for classification with minor modifications suggested by Bain et al. (2010a). The assessment scheme compartmentalizes the prevailing industrial collaborations into four classes or groups: i) intra-firm exchanges, ii) inter-firm exchanges within IEI, iii) inter-firm exchanges outside IEI, and iv) inter-firm exchange for co-generation of products. The fourth type depicts exchanges between facilities owned by the similar entities but are located apart. Besides this, these entities are inherently involved in the different production lines (Fraccascia et al., 2016).

3.3.7. Spatial-temporal Mapping of the byproduct (S)

The industries were grouped into 22 classes according to the PSIC coding scheme (Table 3.2). The complete database was synchronized in the GIS environment for spatial assessment. The user-friendly procedures of GIS enable quicker and efficient assessments. Therefore, the maps were prepared in the ArcGIS environment to identify the locations of industrial units and to comprehend their contextual surroundings. Thus, the user-friendly procedures of GIS enabled assessments and retrieval of the details in an easier and quicker way (Figure 3.2).

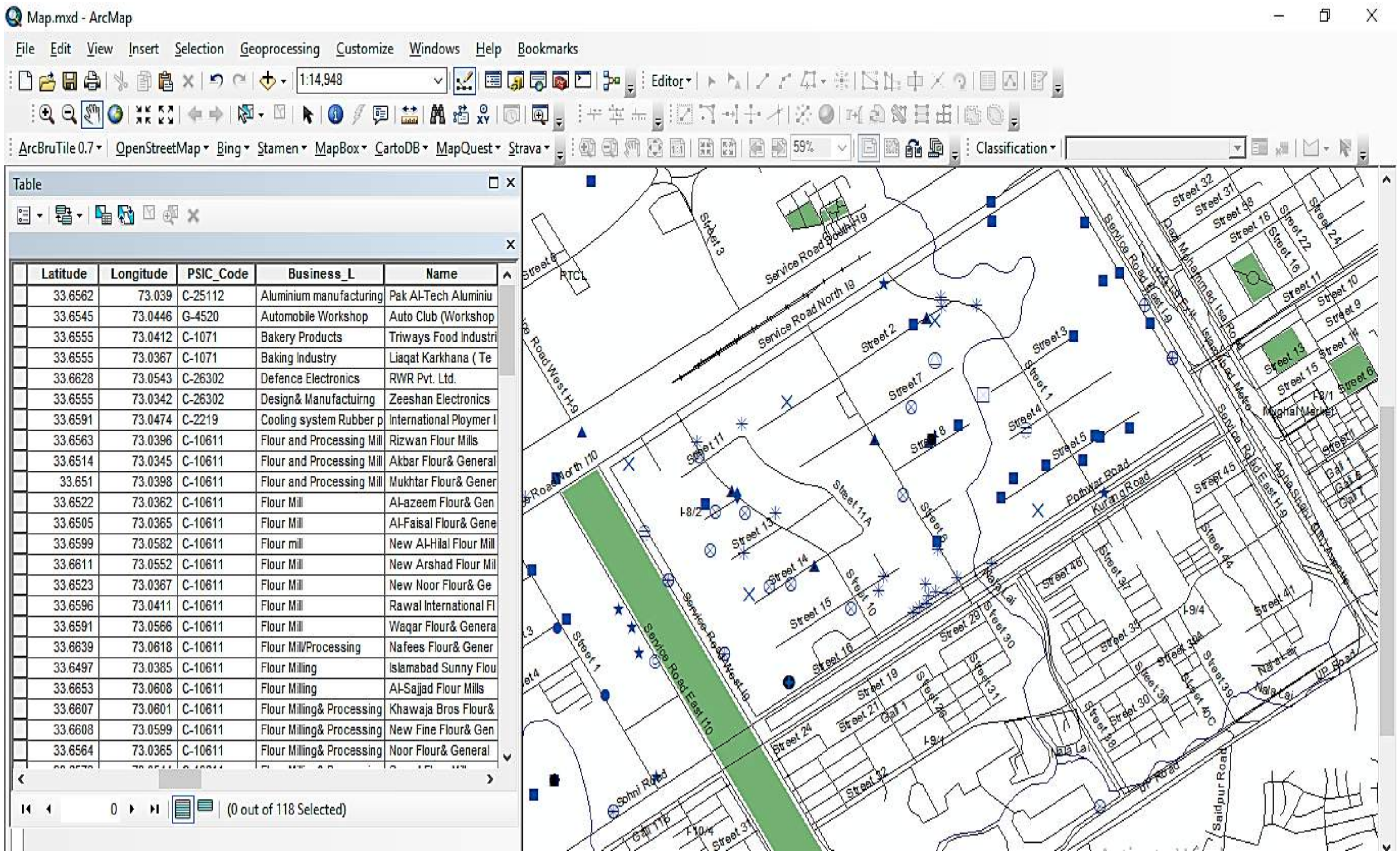


Figure 3.2. GIS map and linked database for by-product synergies

3.4 Environmental and economic benefits of industrial symbiosis

The environmental and economic benefits of industrial symbiosis were assessed by deploying the mechanism of Life Cycle Assessment (LCA). LCA offers a reliable mechanism by maintaining the metabolic records of the materials used in by-product exchanges (Dong et al., 2013b; Martin et al., 2015; Zhao et al., 2018; Liu et al., 2019). A field survey was conducted to assess the prospects of industrial symbiosis in iron and steel industries. The data regarding inputs, processing and outputs from 14 industrial units was collected. For the purpose, a set of three indicators were relied upon. The reported benefits from two different scenarios i.e open loop and closed loop systems, were compared.

The following three indicators deployed for the purpose:

i. Total amount of waste diverted from landfill in case of byproduct exchanges
ii. Total revenue generated from sale/exchange of byproducts
iii. The amount of carbon emission reduced through such linkages

The total amount of byproduct generated and exchanged were calculated from the field data. The data was subsequently averaged to get an estimated figure.

For the second indicator, the market rates of byproducts were obtained from the vendors and exchanging partners. These rates are highly variable. But the annual average statistics provides a pragmatic estimate about the revenue generated from the sale of byproducts.

The assessments pertaining to carbon emissions in both of these scenarios were made by deploying the life cycle assessment method as envisaged by Simapro version 9.1.

The procedural activities of LCA are compartmentalized into four segments in accordance with ISO 14040 methodology. These are the determination of the goal, scope, and system boundary; life cycle inventory (LCI); life cycle impact assessment; and life cycle interpretation. These sub-groups deal with the diverse but interlinked objectives for holistic interpretations.

3.4.1. Goal and scope of the study

The study was designed to estimate the carbon emissions during the iron and steel manufacturing. The estimation in two different scenarios i.e. with and without byproduct exchange synergies were made.

The system boundary included preparation and melting in the induction furnace, continuous casting plant, manufacturing of billets (first-step product), rolling plant, and manufacturing of steel rebar. Functional unit for this study was 1 ton of steel produced. The calculations were made by deploying this functional unit for measurements.

3.4.2. Life Cycle Inventory

For life cycle inventories empirical data was collected from the selected industrial units operating in the IEI. The quantifications were made to assess the amount of waste produced for manufacturing a unit ton of steel. The data was obtained to assess the volume of use of the discarded material. It helped to infer the revenue generated through such partnerships. For the purpose, the information pertaining to the market prices of the byproducts were obtained from stakeholders. Besides this, the secondary data was also consulted such as Ecoinvent 3 and Industry Data 2.0 available with Simapro Version 9.1. The statistics were subsequently relied upon for estimating CO_2 emissions by deploying LCA approaches.

3.4.3. Lifecycle Impact Assessment

Present study compares two scenarios: i) linear flow, and ii) closed loop. Total CO_2 emissions were calculated from the life cycle inventories. The assessment were made on the criteria of differences in the amount of emissions from different scenarios. For the purpose, the global warming characterization method developed by Intergovernmental Panel on Climate Change (IPCC) in 2013 was deployed. The factors are expressed in terms of global warming potential (GWP) for a time horizon of 100 years in $kgCO_2$ eq.

3.4.4. Life Cycle Interpretation

Life cycle inventory results are interpreted for conclusive assessments. The reported carbon emissions from the defined two different scenarios were calculated and compared.

The results helped to formulate the contemporary trends in IS research in Pakistan. These observations also construe about the practical implication for industrial symbiosis, the potentials for by-product exchanges and activities resultant benefits for the economic and environmental resources in Pakistan.

CHAPTER 04

ECO-INDUSTRIAL DEVELOPMENT AND RESPONSES FOR ENVIRONMENTAL RESILIENCE

CHAPTER-4

ECO-INDUSTRIAL DEVELOPMENT AND RESPONSES FOR ENVIRONMENTAL RESILIENCE

4.1. Introduction

The planned and unplanned anthropocentric intrusions for resource exploitation symptomatically delineate the contours of social and ecological resilience. Industrial activities and its concomitant processes significantly augment the speed, scale and magnitude of such interferences in the natural environment. The phenomenon of industrialization is also accountable for contemporary consumer oriented life style. Thereby, the repercussions of industrial activities and the contemporary life style changes are simultaneously depleting the resources and polluting the environment. Resultantly, the consequential impacts are proving stressful for the socio-ecological balance. The scenario demands for postulating out of the box measures for the resilience of social, environmental, and economic assets from a local to a more global scale. In response to these obligations, the emerging approaches embedded in industrial ecology (IE) such as industrial symbiosis (IS) are gaining acceptance as a pragmatic response to addressing these challenges.

The paradigm of IE is now widely being advocated, investigated, implemented and practiced to develop a roadmap for implementing the goal of eco industrial development (EID). Chertow (2007) postulated that the concept of EID envisages synergistic collaborations between industries and their contextual realities. Deutz and Gibbs (2008) opined that EID is the culmination of industrial symbiosis that attempts to integrate economic, social and environmental goals in a concrete form (Deutz and Gibbs, 2008). They envisage that the industrial processing should be synchronised in a way that the output of an industrial activity may be transformed into a more fecund input for subsequent use. Thus, the arrangement will ensure the efficient use of resources without polluting the contextual environment. EID is facilitated by various factors/actors in a geographic setting. These are grouped in three major categories.

1) Spontaneous collaborations as evolved in case of Kalundborg, Denmark.

2) Symbiotic partnerships facilitated by government like National Industrial Symbiosis Program (NISP) in the United Kingdom.

3) Process that is directly sponsored and tailored by the government as in case of China's Circular Economic Model of 2009.

Gibbs et al. (2005) opined that the framework of EID aims at fomenting environment, social and economic dimensions of development in a way that increases business competitiveness. Thus, the framework significantly contributes in waste reduction, pollution control, employment generation and help to improve working environment (Boons et al., 2015). These autogenously driven synergies and partnerships also produce dividends in the form of enhanced economic gains (Chertow and Ehrenfeld, 2012). Therefore, the model is gaining acceptance for promoting symbiotic linkages among the ecological, social and economic components of environment for ensuring the goals of sustainable development (Dara et al., 1996; Thomas, 1997; Geng and Cote, 2002; Chiu and Yong, 2004a; Gibbs and Deutz, 2007; Hatfipour, 2012).

Whereas, these orientations in the industrial activities are incumbent for the resilience of natural and social capital the focus towards such vital aspects leaves a lot to be desired particularly in the developing regions. The late start of industrial activities, lack of vision, inconsistencies, compromises over policies, paucity of technological and financial resources and less supportive environment for innovation are the visible hurdles in the way to EID in the developing regions (Shenoy, 2016). However, the trickledown impacts of EID from the industrialized world, the effects of direct foreign investments (DFIs) and growing concerns for the environmental degradation are imparting the needed stimulus for smart industrial production in the developing countries (Chiu and Yong, 2004b). The increasing volume and significance of DFIs in the economic and infrastructural up-gradation of developing countries are gaining more recognition and momentum (Ali et al., 2017). That makes it obligatory to assess the imprints of DFIs on the industrial sector and economic growth for the conservation of resources and protection of environment.

Therefore, the development models such as "One Belt One Road (OBOR)" warrant comprehensive assessments. These initiatives are conceived to maximize financial and geo-political gains through integration of economic activities. The China Pakistan Economic Corridor (CPEC) is a pragmatic manifestation of such attempts. This framework for regional connectivity not only envisages new found economic opportunities for China and Pakistan but is also meant to support economic growth in the South Asia, Middle East and Central Asia. This multi-pronged and multi-faceted project will help to promote industrial production, connectivity and enhance, simultaneously, the volume of trade among these regions. Besides this, the project will redefine the contours regarding knowledge-sharing, social interactions, industrial production/cooperation and human resource development through regional economic integration.

In this connection, it is pertinent to mention that the densely populated South Asian region is passing through the phases of hyperactive urbanization Ellis, 2016). Resultantly, the urban settlements are gaining more focus as engines of socio-economic development and pivots for innovations. The potentials for economic growth in this region are thus making these urban centers the appropriate locations for investments and industrial activities (Lebel et al., 2007). However, these transformations may accentuate the urban environmental degradation in this region (WHO, 2016) The similar conclusions were drawn in earlier investigations about increasing demands for energy and accompanied emissions (Guttikunda et al., 2003; Mohammed and Krishnendu, 2017; Srivastava, 2017) and proliferation of particulate matter in the urban areas (Guttikunda et al., 2003; Behera and Dash, 2017; Singh et al., 2017; Srivastava, 2017) due to anticipated investments in the form of DFIs.

Therefore, it has become indispensable to regulate urban and industrial expansions for maximizing economic gains without compromising urban environmental resilience. This will ensure a realization of the goals of sustainable industrial development in Pakistan. However, the unplanned/unregulated processes of urbanization and industrialization are encouraging the "pollute now – clean up later" (Lebel et al., 2007) approaches. The emerging scenario demands for corrective and regulatory measures. In this connection, the paradigm of IE and associated mechanisms embedded in EID offers doable perspectives to strive for the desired objectives. A fact, universally acknowledged, is that the EID must be strengthened either through formal legislation (Qinghua et al., 2007) or empowering it as a regulator and facilitator (Chiu and Yong, 2004a; Bain et al., 2010b). Regrettably, the domains such as IE and EID fail to attract the attention of policy makers, planners and researchers in Pakistan. These initiatives and many more, are incumbent for ensuring cleaner production and conservation of resources for a more resilient environment (SWITCH-Asia, 2013).

Therefore, the emerging scenario in the wake of CPEC, nesscitates a thorough examination of the potentials and prospects of EID in Pakistan. A concentrated effort, in this regard is cardinal from the government, academic and industrial sectors, as they are the most relevant stakeholders with regard to EID (Paquin et al., 2014) and its consequent benefits from CPEC. The current study is based upon the assessments of strengths, weaknesses, opportunitites and threats, henceforth refered to as the SWOT analysis. The findings of the study will provide a strategic framework in consultation with the concerned intelligentsia, industrial quarters and government institutions for stimulating EID in the contextual setting of Pakistan. The study will also help to materialize the goals of socio-ecological sustainability in this country. Besides this, it will contribute to overcome the knowledge gap pertaining to EID in developing countries.

4.2. Results

The findings of the study divulge that the economy of Pakistan is in its recovery phase. The improving GDP growth rate of 5.79 % in the fiscal year 2017-18 (GoP, 2018) supports these observations. The outcomes such as the high correlation between GDP growth rate with services (r = 0.8) and manufacturing sectors (r = 0.7) (Figure 3.1) also corroborate the notions that the economy of Pakistan is diversified. These signs of improvement in the economy of Pakistan are attributable to the improvement in regional security, economic reforms and increased flow of DFIs.

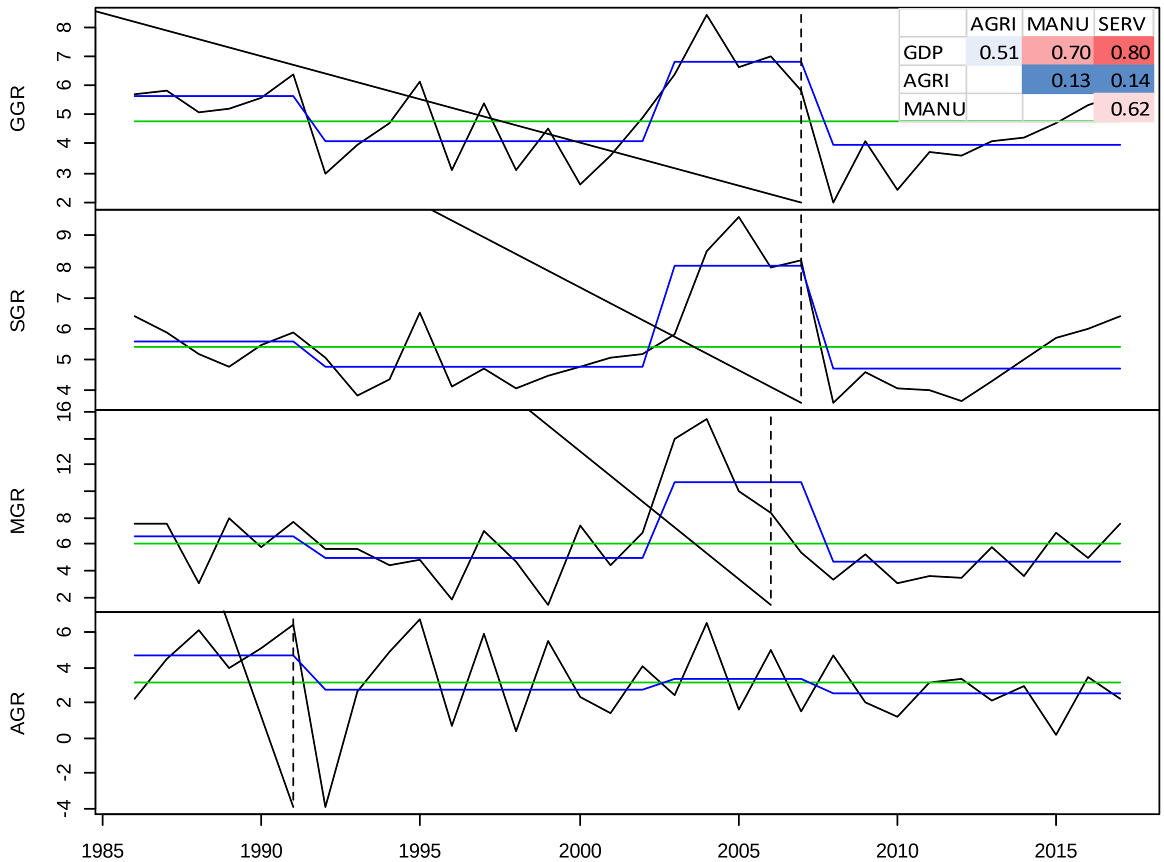


Figure 4.1. Pakistan's annual economic growth.

GGR (GDP growth rate), SGR (Services growth rate), MGR (Manufacturing growth rate), AGR (Agricultural growth rate). Annual growth rates (black curves); Structural breaks (dashed lines), linear trend (green = no change scenario; blue = structural breaks).

4.2.1. Direct Foreign Investments (DFIs) and Pakistan

The DFIs play a significant role in the economic restructuring and development in the current phase of economic globalization (Chiu and Yong, 2004b; Shenoy, 2016). These investments provide financial impetus, ensure technological support and extend awareness for innovations in the developing economies. Statistics indicates (Table 4.1) the increasing volume and flow of DFIs towards Pakistan in recent years. Table 4.1 also reveal that a significant proportion of DFIs is from China especially after the CPEC agreement in 2013.

Table 4.1. Annual Net Direct Foreign Investment in Pakistan (in $ Millions)

Years	Total DFI	DFI From China
2009-10	2150.8	3.6
2010-11	1634.8	47.4
2011-12	820.7	126.1
2012-13	1456.5	90.6
2013-14	1698.6	695.8
2014-15	987.9	319.1
2015-16	2305.3	1063.6
2016-17	2746.8	1211.7
2017-18	3092.0	1812.6

(Source: Board of Investment, retrieved from *http://invest.gov.pk/ForeignInvestmentinPakistan.aspx*)

4.2.2. Special Economic Zones and industrial activities

The origin of special economic zones (SEZs) is rooted in the theory of indusrial location proposed by Weber. It emphasizes the premise that "industrial activities need specialized locations" (Dhingra et al., 2009). The developmet of SEZs in Pakistan is governed by the SEZ Act, 2012. The act was subsequently amended in 2016 and operationalized through SEZ Rules, 2013. The, Clause 1(d) of Section 16 in SEZ Act 2012, envisaged that the "*the developers must undertake to comply with all environmental, labour and other applicable legislations in force in Pakistan*" for ensuring economic development and environmental resilience. Under this Act, seven economic zones have been notified (Tabe 4.2). In addition to these seven SEZs, the government also has identified and proposed 34 Economic Zones, 29 Industrial Zones and 21 SEZs in different part of Pakistan (Ali et al., 2017).

Table 4.2. Seven SEZs approved and operational in Pakistan

Special Economic Zones (SEZs)	Area
Khairpur Special Economic Zone, Sindh	136 Acres
Korangi Creek Industrial Park, Sindh	240 Acres
Bin Qasim Industrial Park, Sindh	930 Acres
Quaid-e-Azam Apparel Park, Sheikhupura, Punjab	1536 Acres
M-3 Industrial City, Faisalabad, Punjab	4356 Acres
Value Added City, Faisalabad, Punjab	255 Acres
Hattar Economic Zone, Haripur, KP	424 Acres

4.2.3. CPEC and industrialization in Pakistan

Sustainable development is the guiding principle for the initiatives being launched under the CPEC (2017-2030). The investments under this “game-changer plan” are meant to develop the infrastructure, the energy sector, and to enhance industrial cooperation for economic growth. Various projects aim to harness the indigneous resources endowments of the country by expanding the industrial base of Pakistan through improved connectivities. Therefore, the focus towards the creation of new industrial clusters on the principles of eco-industrial development is gaining momentum. In this connection, the development of nine special economic zones is under progress (Table 4.3). The Center of Excellence for CPEC, an official policy based research institute, proposed to convert these SEZs into green SEZs in 2017 for stimulating eco-industrial development in Pakistan (Center of Excellence for CPEC, 2017).

Table 4.3. Special Economic Zones (SEZs) approved under CPEC

Special Economic Zones	Area (Acres)	Type of activity
Rashakai Economic Zone , M-1, Nowshera	1000	Fruit/Food/Packaging/Textile Stitching /Knitting
China Special Economic Zone Dhabeji	1000	To be determined during feasibility stage
Bostan Industrial Zone	1000	Fruit Processing/Agriculture machinery Pharmaceutical/ Motor Bikes Assembly / Chromites/ Cooking Oil / Ceramic industries/ Ice and Cold storage/ Electric Appliance / Halal Food Industry
Allama Iqbal Industrial City (M3), Faisalabad	3000	Textile/ Steel/ Pharmaceuticals/ Engineering/ Chemicals/ Food Processing/ Plastics/ Agriculture Implements Etc
ICT Model Industrial Zone, Islamabad	200-500	Steel/ Food Processing/ Pharmaceutical & Chemicals/ Printing and Packaging/ Light Engg. Etc.
Industrial Park at Port Qasim near Karachi	1500	Steel/Auto & allied/Pharma/Chemical/ Printing and Packaging/Garments etc.
Special Economic Zone at Mirpur,AJK	1078	Mixed Industry
Mohmand Marble City		
Moqpondass SEZ Gilgit-Baltistan	250	Marble / Granite/ Iron Ore Processing/ Fruit Processing/Steel Industry/ Mineral Processing Unit/ Leather Industry

4.2.4. Initiatives for EID in Pakistan

The assessments based upon content analysis of policy documents were made to decipher the orientations towards EID in Pakistan. The inclinations towards EID are attracting focus due to Pakistan's commitments and engagements at international level such as the 3R Forum and World Business Council for Sustainable Development (WBCSD). These forums facilitate to institutionalize/formulate the policy instruments for promoting industrial symbiosis as a means towards eco-industrial development (https://www.env.go.jp/recycle/3r/en/index.html).

In this context, Pakistan has adopted Sustainable Development Goals (SDGs) as national development goals. The goals focus on sustained industrial growth and stress on formulating strategies for ensuring eco-friendly industrial production (GoP, 2014). However, these policies need instutional and regulatory support. The review was also made to evaluate the initiatives taken by the government in partnership with international organizations like SWITCH-Asia (SWITCH-Asia, 2010). The significant findings regarding the nature of industrial activity, co-partners involved in the processing, the timeframe of the selected project and the significant outcomes have been reported under different project reports as summarized in Table 4.4.

Table 4.4. EID initiatives in Pakistan

Project Title	Sector	Co-Partners	Project Duration	Outcomes
Sustainable Cotton Production in Pakistan's Cotton Ginning SMEs [1]	Cotton ginning SMEs	WWF-Pak, WWF-UK, Pakistan's Cotton Ginners Association, Better Cotton Initiative, National Textile University, Faisalabad	2012-2015	At least 500 cotton gin SMEs in Pakistan recognize the benefits of sustainable cotton production and consumption and 40% of these commit to more sustainable production practices, in line with agreed better ginning practice guidelines, and supported by the procurement practices of European retailers.
High-pressure Cogeneration (HPC) for Sugar Sector in Pakistan [2]	Utilities Sector	Iqbal Hamid Trust (IHT), sequa GmbH, The Energy and Resource Initiative (TERI), Pakistan Sugar Mill Association (PSMA),	2014-2018	1. Sustainable production of energy through replication of existing HPC technologies in the sugar sector. 2. Sustainable consumption of bagasse by supporting sugar mills in the adoption of HPC technology. 3. Technology standardization, enabling access to finance, and mobilizing of relevant public sector authorities for the formulation of a conducive regulatory regime.
Sustainable and Cleaner Production in Manufacturing Industries [3]	Textile & leather industries	Verein zur Förderung des Technologietransfers an der Hochschule Bremerhaven e.V. (TTZ), Collaborating Centre on Sustainable Consumption and Production (CSCP), Iqbal Hamid Trust (IHT), Cleaner Production Institute (CPI)	2009-2013	1. Reduction of GHG emission: 2. Textile sector: 43,000 tons of CO_2 per year 3. Leather (Tanneries): 3,000 tons of CO_2 per year 4. Resource efficiency: 5. Leather Sector: 5% water reduction, 36% electricity reduction, 20% gas reduction

[1] https://www.switch-asia.eu/news/pakistans-sustainable-cotton-production-goes-forward/
[2] https://www.switch-asia.eu/projects/hp-cogen-pak/
[3] https://www.switch-asia.eu/projects/sci-pak/

Project Title	Sector	Co-Partners	Project Duration	Outcomes
				6. Textile Sector: 15% water reduction, 42% electricity reduction, 20% gas reduction 7. 5 pilot projects delivered following impact: 8. Caustic recovery plant: 30% reduction in caustic soda usage 9. Waste Heat Recovery Boiler: 20% reduction is the fuel consumption for steam generation 10. Rice Husk Boiler: 100% fuel switch to carbon neutral fuel. 11. Chrome Recycling: 20% reduction in Chrome Usage 12. Oxygen Trim System: 7% reduction in fuel consumption. 13. 50% Reduction of accidents
Citywide partnership for sustainable water use and water stewardship in SMEs in Lahore Pakistan[4]		WWF Pakistan, Cleaner Production Institute, WWF-UK	2013-2015	1. 300 processing and manufacturing SMEs in the target area have enhanced understanding of Better Water Management Practices (BWMPs). 2. 6,75 high water using SMEs have increased water management capacity, and 3. 25 SMEs is implementing BWMPs, supported by multi-stakeholder city level water partnership

[4] https://www.switch-asia.eu/projects/water-stewardship-pakistan/

4.2.4.1. *The devolution of power and EID*

The 18th constitutional amendment envisaged devolution of power, shifting decision making from the federal to the provincial domain.These constitutional revisions have significant bearings on the regulatory and institutional mechanisms for eco-friendly industrial processing in the country. Therefore, assessments were made to compare the salient characteristics of policy and regulatory frameworks regarding the pre and post "devolution of power" scenarios. The critical findings regarding pre-devolution initiatives for environmental protection at national level have been summarized in Table 4.5 and post-devolution initiatives at provinical level in Table 4.6. These were also relied upon for qualitative assessments and interpretations. The findings divulged that the regulatory framework for environmental protection in Pakistan is more inclined towards controlling pollution rather than encouraging novel solutions for environmental resilience. The assessments construed that the lack of capacity and financial constraints at provisional/local level are the observable hindrences.

Table 4.5. Pre-devolution initiatives for environmental protection at national

Legal Instrument	Initiative	Details
Pakistan Environmental Protection Act, 1997[5]	Section 5: Establishment of Environmental Protection Agency	Pak-EPA was established as a regulatory authority with jurisdiction at the federal level.
	Section 6: Functions of Environmental Protection Agency	Section 6, Clause 1 (e), (f) deals with the development and enforcement of National Environmental Quality Standards (NEQS) for effluents and discharge. 1(g) deals with the establishment of standards for ambient water, air quality and land. 1(n) deals to assist the local councils, local authorities, Government Agencies and other persons to implement schemes for the proper disposal of wastes so as to ensure compliance with the standards established by it;
	Section 11: Prohibition of certain discharges or emissions	Impose pollution charge on activities discharging above NEQS
	Section 13: Prohibition on import of hazardous waste	Hazardous waste and hazardous substance rules 2016 are in draft stage yet.
	Section 14: Handling of hazardous substances	Hazardous waste and hazardous substance rules 2016 are in draft stage yet.
Self Monitoring and Reporting (SMART) Rules, 2001[6]	Section 4: Classification of industries	Classify industries in category A, B, and C according to the level of pollution and requires each industry to submit their environmental monitoring reports periodically to Pak-EPA.

[5]Pakistan Environmental Protection Agency, Ministry of Climate Change, Pakistan. 1997. *Pakistan Environmental Protection Act, 1997*. Islamabad

[6]Pakistan Environmental Protection Agency, Ministry of Climate Change, Pakistan. 2001. *National Environmental Quality Standards (Self Monitoring and Reporting by Industry) Rules, 2001*. Islamabad

Hazardous Substance Rule (Draft, 2003)[7]	Identify 242 hazardous substances and require companies dealing with these waste to obtain a license.
National Environmental Policy of Pakistan, 2005[8]	Enforcement of NEQS and SMART Rules, Financial and other incentives like reduction/elimination of tariffs, low-interest loans, appreciation certificates and awards Support upgrading of technology, adoption of cleaner technology, and implementation of pollution control measures and compliance with environmental standards
Hazardous Waste and Hazardous Substance Rules, 2016 (Draft)	Provide a list of hazardous substances and require licensing and reporting from companies dealing with these substances.

Table 4.6. Post-devolution initiatives for environmental protection in Pakistan at provinical level

Province	Organization Dealing with	Initiatives
Punjab	Punjab Environmental Protection Department	Punjab Environmental Protection Act 1997 (amended 2012)
Sindh	Environment and Alternate Energy Department	Sindh Environmental Protection Act, 2014
Balochistan	Environment, Sports and Youth Affairs Department	Balochistan Environmental Protection Act, 2012
Khyber Pakhtunkhwa (KPK) - Wildlife Department	Forestry, Environment and Wildlife	Environmental Protection Act, 2014
Azad Jammu Kashmir	Azad Jammu Kashmir Environmental Protection Agency	
Gilgit Baltistan	Gilgit Baltistan Environmental Protection Agency	Giglit Baltistan Environmental Protection Act, 2016

4.2.4.2. EID and Industrial sector in Pakistan

The acquisition of ISO-14001 certification indicates the proclivity for resource conservation and environmental sustainability. The conceptual paradigm of ISO-14001 stresses on the synergistic interactions between and among different components/processes in the industrial activities. The findings (Figure 4.2) portray that the inclinations towards ISO 14001 certification are gaining monentumin in Pakistan since 1990.

[7]Pakistan Environmental Protection Agency, Ministry of Climate Change, Pakistan. 2003. *Hazardous Substance Rules, 2003 (Draft)*. Islamabad
[8]Ministry of Climate Change, Pakistan. 2005. *National Environmental Policy of Pakistan*. Islamabad , ibid.

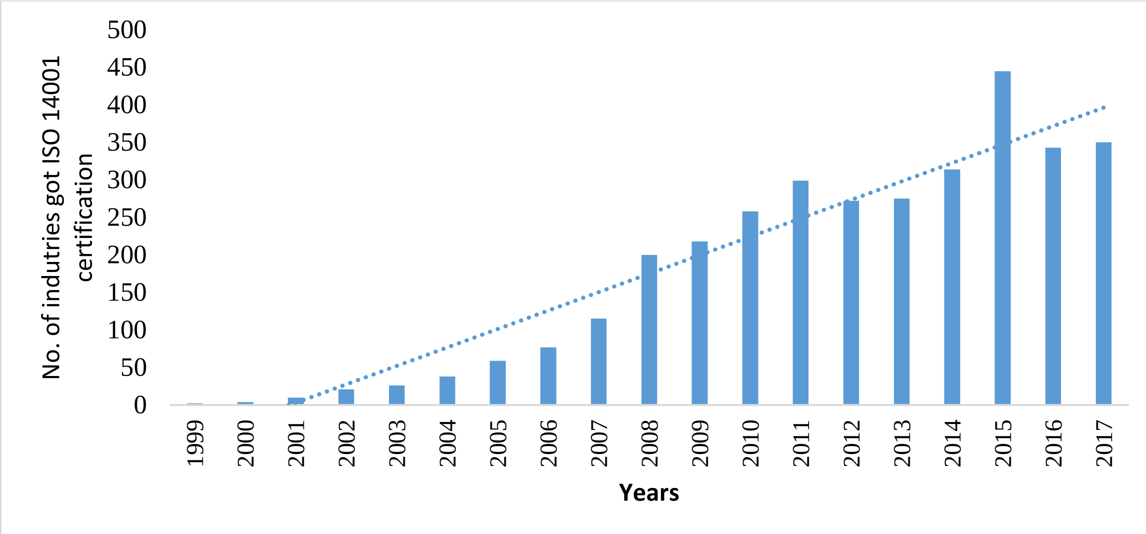


Figure 4.2. Trends in ISO 14000 certifications by industry in Pakistan

These inclinations are incumbent to fullfilling social responsibilities and international obligations in the wake of contemporary environmental challanges. These tendencies are particularly more common in all industry-oriented transactions dealing with the international markets (Table 4.7)

Table 4.7. EID intitiatives taken by industy in Pakistan

Industry	Initiative	Collaborating Partners	Benefit
Artisitice Milliner[9]	Closed Loop Denim	I:CO	1 million meters per month of closed loop denim manufacturing.
Tetra Pak[10]	Circular Economy	CE100	Responsible Sourcing The average renewable content of carton packaging material is around 75 percent. All Tetra Pak carton packages are recyclable, and over 46 billion were recycled in 2017 alone
Pepsi Co Pakistan			over 100 million pounds of packaging material from the market in 2015
Saif Holding Pvt Ltd[11]	Lafarage Group of Indsutries		Refuse derived fuel
ICI Pakistan Ltd	Waste Minimization at Soda Ash Plant		Waste generated by the older Coal fired boiler was used as salvage and reused as fuel in new boilers.[12]
Interloop Pvt Ltd	Sustainable material Consumption		Utilized 1,427 tons of recycled yarn in 2017 thus reducing waste.[13]

[9]http://www.artisticmilliners.com/sustainability.php
[10]https://www.tetrapak.com/sustainability/circular-economy
[11](https://www.psx.com.pk/newsattachment/057895.pdf
[12] ICI Pakistan Ltd. 2018. Sustainability Annual Report.
[13]http://www.interloop-pk.com/planet-2/

4.2.4.3. Small and medium enterprises (SMEs)and EID

SMEs are an integral part of industrial production in Pakistan. The Census of Manufacturing Industries (CMI) projected that these manufacturing units are capable of contributing 105 million US dollars through the utilization of industrial salvage, scraps and industrial waste (GOP, 2006). However, the end users are facing problems in implementing IE related initiatives. Their problems accentuate due to lack of awareness, resource-availabilty and technical support. The industries are scattered in the urban areas without any planning. Besides this, the existing industrial estates in the country were not designed on the principles of EID to accomodate utlitity sharing or to achieve the zero emission targets. Thus, the situation is not encouraging for the SMEs to include eco-industrial initiatives in their ambit. However, the findings (figure 4.3) helped to conjecture that the potential market for the waste recycling and reuse exists for initiating/promoting EID in Pakistan.

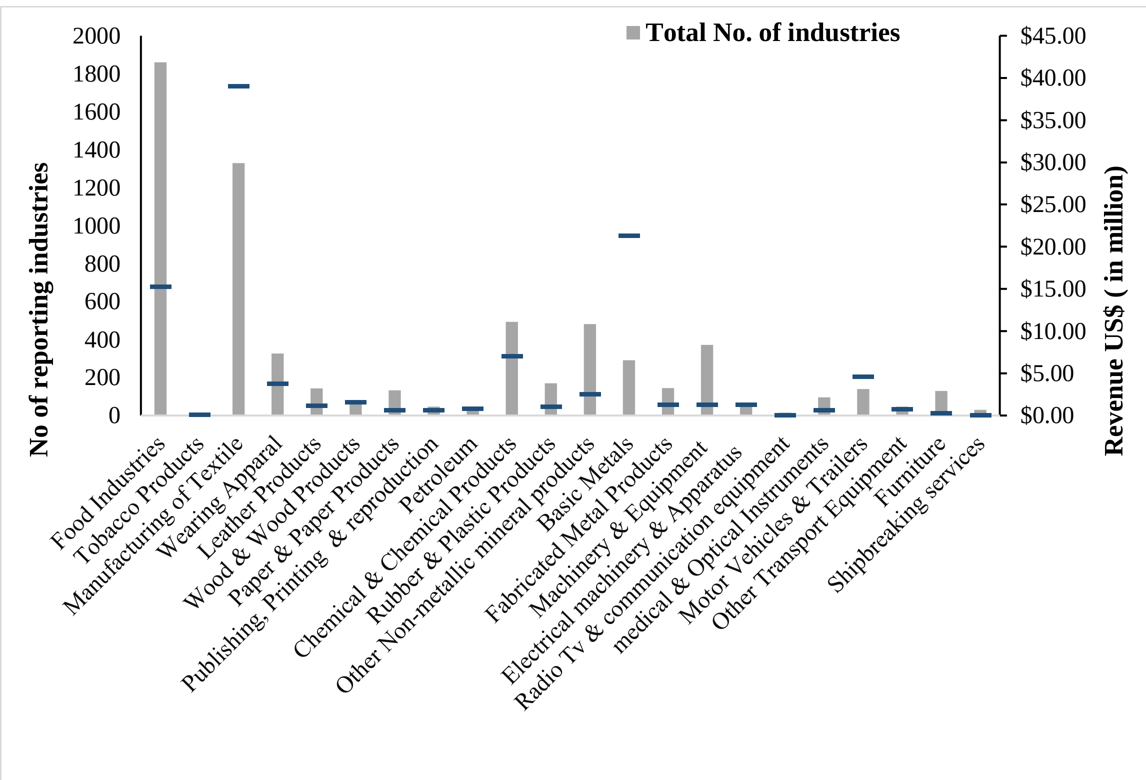


Figure 4.3. Annual revenue generated from the sale of industrial waste in Pakistan

4.2.4.4. Academia and orientaion towards EID

Investments in quality education are imperative for the knowledge economy and economic growth. There are 167 tertiary level degree awading institutions (DAIs) functioning under the regulatory control of HEC. HEC is responsible for devising and updating the curricula for these DAIs in response to societal demands and market needs. Since its inception in 2004, HEC had revised 140 curricula of various disciplines. Whereas, the curricula provides broad guidelines to the DAIs for their academic programs, the DAIs are, in turn, autonomous to design these programs as they deem appropriate.

The first course titled "Industrial Ecology" was introduced in Pakistan as an elective course in the curriculum of the graduate program for environmental science in 2009 (HEC, 2009). Our studies revealed that 40 different courses, focusing on or related to IE, are being taught in 20 out of the total 167 DAIs in Pakistan (Appendix III). However, the majority of these courses are taught in the different programs of environmental science at graduate level. The other disciplines offering IE in their curricula are: Environmental Engineering (03); Chemical Engineering (02); Process Engineering (01); Design and Manufacuring (01); Energy and Environmental Management (01) and Agriculture Engineering (01). The locational map (Figure 3.4) of these DAIs portrayed that the majority of these institutions are located in the industrialized regions. It substantiates the notions that the course uptake is higher in the areas where the concept is already in practice.

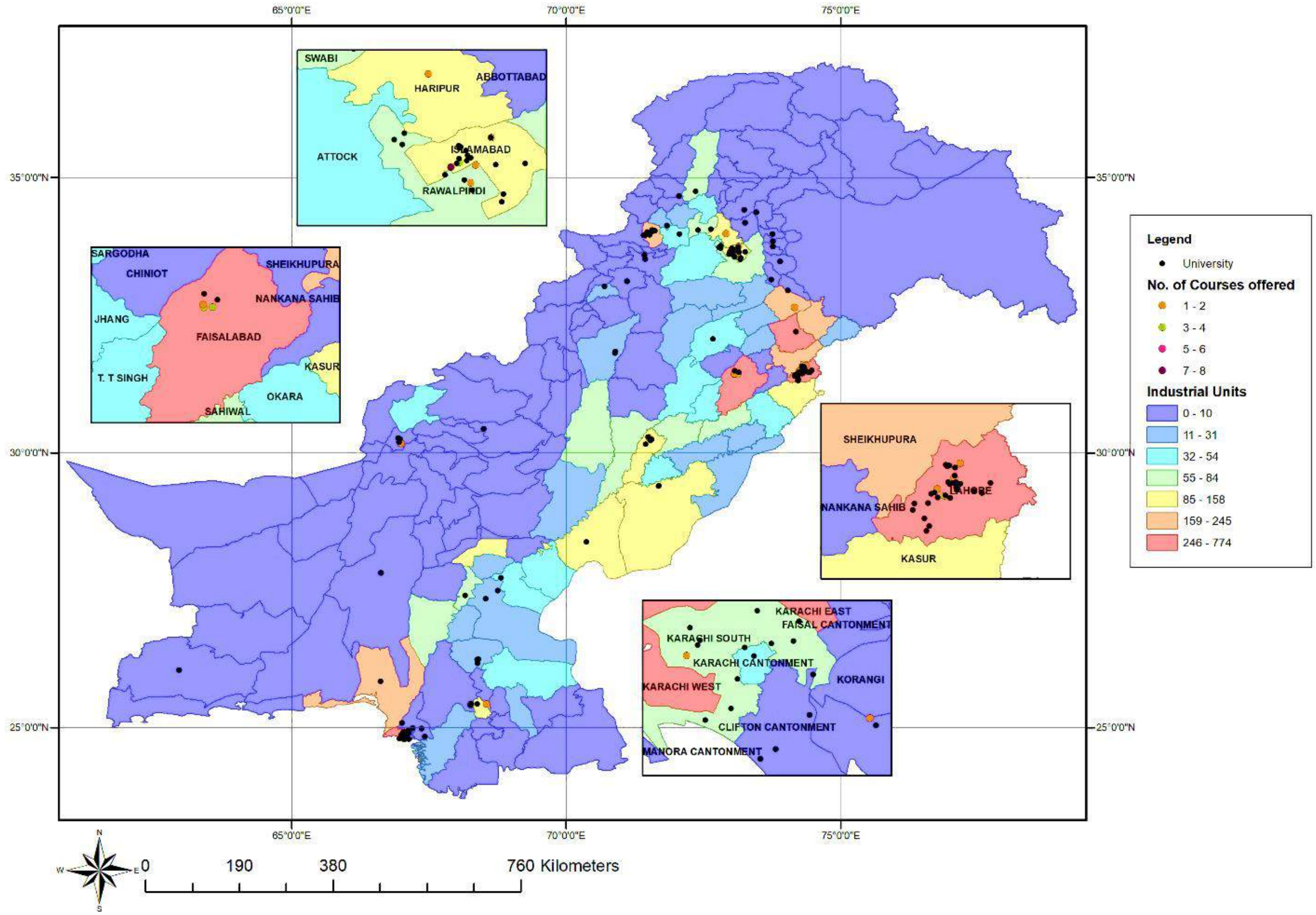


Figure 4.4. Spatial prevalence of IE related courses and number of industries in Pakistan

Besides this, the research thesis of these DAIs related to IE were also reviewed for qualitative assessments (Appendix IV). The content analysis portrayed that the contemporary research initiatives are more inclined towards pollution control, waste management, and on postulating remediation strategies for industrial waste. Whereas, IE was highlighted as a possible solution instead of the primary topic of research.

4.3. Discussion

The agenda for development in Pakistan is refered to as “Vision 2025”. The objectives of the vision are now known as the national development goals.The document intends to realise the all inclusive economic growth of the country. The vision targets to achieve and sustain the economic growth rate of 8% during 2018 - 2025. Steady and balanced economic growth is required to eradicate poverty, to ensure social development and environmental sustainability in the country. The attainment of these targets is obligatory to fullfill international obligations such as those associated with sustainable development goals (SDGs). It necessitates for synchronised regional and sectoral advancements from all the component of the economy. Therefore, the assessments regarding GGR (GDP growth rate); Services Growth Rate (SGR); Manufacturing Growth Rate (MGR) and Agricultural Growth Rate (AGR) are incumbent for evaluating the orientation of economic progression. The information pertaining to the ensuing structural readjustments/transformations and understandings about the linear progressions in and among the various component of economy are important for comprehensive assessments.

The recent GDP growth of 5.3% during the fiscal year 2016-17 and the anticipated DFI opportunities being offered by CPEC are expected to further accelerate economic and industrial growth in Pakistan. Besides this, the initiatives for nine SEZs and other similar measures for integrated industrial development offer promising opportunities to integrate EID in the agenda for development. However, the ambiguities and inconsistencies in policies, poor governance and lack of research based decision making are responsible for the “pollute now and clean later” mindset in the industrial sector. The rules and regulations are more focused on pollution control rather than pollution prevention. The resultant environmental degradation and resource depletion warrants corrective measures. The critical findings of the current study based upon SWOT analysis divulge the following for review and consideration.

4.3.1. The challenges and opportunities regarding EID

The assessments based upon SWOT analysis provide an opportunity for postulating pragmatic measures to ensure EID. The SWOT analysis for the current study is based on the information retrieved from the industrial sector, government institution and academia through a consultative process (Figure 4.5). The analysis enables to focus on an efficient use of resources, to bridge the gaps, to concentrate on the prospects and to address the challenges for eco-friendly economic development.

4.3.1.1. Strengths

The findings indicate that the economy of Pakistan is in the process of recovery due to macro-economic and structural reforms, dwindling oil prices and gradually improving regional security (2016). The projected DFIs of 62 billion dollars through CPEC for energy and infrastructural developments and the development of 9 special economic zones will also contribute towards industrial development. The cumulative outcomes will stimulate innovations and skills to promote industrial symbiosis as a policy to promote EID in this country. These postulations substantiate the assertions of Chiu and Yong (2004a), and Shenoy (2016) that sustainable economic growth acts as a push factor for promoting IE in the developing economies.

The outcomes of this study divulge that the state institutions are motivated to achieve the goal of sustainable economic growth (GoP, 2014). The recent measures such as the devolution of power through constitutional amendments, deregulation of state entities and encouragement of private sectors etc. are the pragmatic measures for promoting industrial growth. Besides this, the site specific measures based upon contextual realities, yield dividends, increase resource efficiency and promote EID. In the post devolution scenario, there is a greater room for the stakeholders to act and interact for postulating strateges at local and regional levels.

The findings based upon content analysis portrayed the growing realization about the role/importance of integrated industrial development as compared to the past decade. The acquisition of ISO 14001 certification corroborates the notions that the corporate sector in Pakistan is becoming more aware about the benefits of cleaner production, resource efficiency, and utility sharing techniques. Besides this, the initiatives from the Federal Ministry of Climate Change, HEC and constructive engagements with international fraternity also encouraged such tendencies.

In this connection the role played by HEC is very important. The HEC took several initiatives to support research and encourage linkages between the academia and industry for intensifying symbiotic interactions. Resultantly, the domain of IE is getting recognition among the stakeholders as a pragmatic option to promote industrial activities without damaging the environment (Marstrander et al., 1999; Ning et al., 2007; Stephens et al., 2008; Geng et al., 2009a; Aurandt and Butler, 2011). Therefore, the DAIs are offering more courses to cope with the industrial waste and to improve resouce efficiency in tertiary level education (Filho, 2002; Staniškis and Arbaciauskas, 2003; Sharma, 2009). However, these endeavours are more inclined and focused towards theoretical postulations instead of practical problem solutions.

Figure 4.5. SWOT analysis of the existing condition for EID in Pakistan

4.4.1.2. Weaknesses

The knowledge of the odds is the first step towards success. The findings rendered that the lack of clarity and compromises over policies due to non-conducive regulatory regime are the observable impediments in the way of EID in Pakistan. These barriers are narrowing the horizons and hence strangulating the progress of EID in Pakistan. Therefore, immediate attention is required to overcome the gaps/lacunas in the policy frame work and in management practices. It necessitates the detailed assessment of contextual needs and potentials for informed decision making. The present findings (Figure 4.4) construe that the scattered distribution of industrial activities in Pakistan is a challenge for integrated management and infrastructural development. The physical segregation of industrial activities discourages all possibilities of collaborations in terms of exchange of materials and sharing of utility. The recent focus on SEZs is a step in the right direction but the situation demands responsiveness and resolute efforts.

Although, the numerical increase in the DAIs and their students is considered a healthy omen for the creation and dissemination of knowledge, yet, their contributions do not receive the requisite acknowledgement in the decision making processes. The conceivable explanation is rooted in the facts that the curricula in DAIs is more inclined towards theoretical paradigms instead of practical problem solution. Besides this, the academic research is more skewed in favor of curative technologies as compared to preventive methods for environmental protection.

Regrettably, the industrial sector is proving less responsive to adopting modern technology. The current regulatory regime only focuses on penalizing industries for non-compliance and does not offer rewards for compliance. The government should offer monetary incentives for supporting eco-friendly technologies through tax incentives or tariff reductions. The incubation centers meant to develop indigenous solutions are almost non-existent or non-functional. Thus, unflinching focus is required for promoting innovations and out of the box solutions.

4.3.1.3. Opportunities

The outcomes of the study portrayed that the regional and global economic equations are encouraging the infrastructural and industrial development in Pakistan. The financial and technical assistance from such international engagements as SWITCH-Asia, UNIDO and UNEP platforms are proving as catalyst for integrated and cleaner production (Schandl et al., 2012). The obligations associated with international trade and bindings attached with environmental treaties like Kyoto protocol, SDGs etc. seem cumbersome yet inevitable for EID in Pakistan. The investments and transfer of technology through CPEC will further augment the efforts for industrial development (Shenoy, 2016). In this connection, the intended development of nine economic zones will boost eco-friendly industrial proclivities in the country. These economic zones can be taken as a pilot eco-industrial model (Khisa, 2018). Whereas, these engagements are pouring new concepts, tools and technologies from partner entities, the government must ensure to provide a conducive environment for investment in the industrial sector. The 18th Constitutional Amendment provides the much needed avenues to formulate policy and regulatory measures at regional level for eco-friendly initiatives. It offers an opportunity to synchronize National Environmental Quality Standards (NEQS) according to contextual needs in consultation with the industrial sector.

4.3.1.4. Threats

The geo-strategic location of Pakistan is a boon as well as a bane for DFIs and economic development. The volatile geo-political environment in the region due to war against terrorism, instability in Afghanistan and the recent upsurge in Indo-Pak hostilities are posing severe challenges for the regional economic development. These hostile conditions are not conducive for DFIs. The successive governments are forced to entertain security requirements from the available financial resources. Consequently, Pakistan is forced to concentrate on short-term projects for industrial development instead of long-term paradigm shifts such as to promote EID. Therefore, the containment of terrorism and de-escalation in the regional tension is mandatory for sustainable industrial growth, economic stability and peace. Besides this, the political instability in Pakistan is responsible for the observed focus towards the more tangible projects rather than investing in the long-term objectives for economic sustainability. Although, these tendencies are changing in recent times, however, a lot more is required.

The introduction of ambiguous environmental laws after the 18th amendment are also causing confusions. The dissimilarities in the parameters among the federating units concerning NEQS may prove counterproductive for balancing industrial progression in the country. These anomalies are, thus, potential challenges and require rectification.

The rapid population growth and the limited resource base are the real challenges for a developing country like Pakistan. The increasing population pressure acts as a barrier for industrial development and innovation. Therefore, policy and regulatory measures are required to change the perspective about human population growth.

CEPC can open up new horizons for eco-friendly industrial development in Pakistan. Pakistan has many vital advantages to support the development of EID, however a key weakness is the lack of alacrity to encourage and facilitate such developments through a systematic strategy. Therefore, synchronized efforts are needed to overcome these lacunas that are hindering the practical implementation of such concepts as IE and Circular Economy (CE). These initiatives are incumbent for ensuring economic and industrial development without impacting the natural environment.

4.4. Conclusion

Pakistan can serve as a hub and corridor of trade due to its geostrategic location. The dividends are dependent on an investment in infrastructure, enhancing competitiveness, promotion of export-oriented industry and focus on knowledge economy. Although industrial activities are responsible for environmental and health problems, the inclinations, fortunately, are being focused on zero emission targets. The expected activities under CPEC can usher in new pathways for trade and EID in Pakistan. Pakistan has many key strengths to support the development of EID, however a key weakness is the lack of facilitation to encourage such developments. Therefore, synchronized efforts are needed to overcome these threats. These initiatives are incumbent for ensuring economic and industrial development for a resilient natural environment.

4.5 Recommendations

The following are the recommendations for the success of EID in Pakistan;

1) The dimensions of EID in Pakistan are diverse. While on one hand, the fast economic pace of development through DFI under CPEC is unprecedented and hitherto unequalled, the internal security and political instability complicates the implementation of EID. Therefore, the above-mentioned threats demand comprehensive strategizing.
2) EID should be adopted as a holistic approach and should be integrated in mainstream policies for economic development instead of a stand-alone tool to overcome environmental pollution.
3) EID involves many different aspects that fall under the domain of many different organizations among which the academia, the corporate world and government are key players. Besides these, non-traditional partners like the Chamber of Commerce and Industries should be involved in policy making.
4) It is indispensable to improve compliance and performance of industries against existing regulations. This can be achieved by increased monitoring and enforcement. It requires the capacity building of the staff and institutions in terms of knowledge and technical equipment.
5) Integrating IE in tertiary level education and vocational training will productively contribute to industrial activities.
6) Promoting research and development for improving indigenous technologies for waste and byproduct utilization.
7) The government should apply a two-pronged strategy, i.e. the strict enforcement of the policies and pledging financial incentives, technical assistance, and opportunities for capacity building to achieve the objective of sustainable industrial production.
8) The government should encourage the transfer of environmentally sound technologies by reducing duties and providing incentives.
9) Industries have a tendency for economic collaboration to maximize economic gains. The government should facilitate this by providing resources and platforms.

CHAPTER 05

IDENTIFICATION, CHARACTERIZATION AND CLASSIFICATION OF BYPRODUCT EXCHANGE SYNERGIES

CHAPTER-5

IDENTIFICATION, CHARACTERIZATION AND CLASSIFICATION OF BYPRODUCT EXCHANGE SYNERGIES

5.1. Introduction

Manufacturing activities are on the rise in Pakistan and likely to further accelerate under CPEC regime. The expansion and growth in the industrial sector have its own ramifications for the transforming economy and natural environment of Pakistan. The lack of capacity building, financial restraints and resource limitations are the visible impediments towards eco-friendly industrial development in developing countries (Abid and Ashfaq, 2015). Whereas, the initiatives for industrial and economic growth are incumbent in the present age of market economy, the scientific communities also stress on the measures for ecological resilience and social sustainability (O'Rourke et al., 1996; Athanassiadis, 2016). Therefore, the paradigm of "triple bottom line" was conceived to ensure the goal of economic development without compromising the sustainability of the socio-ecological environment. The model stresses on the prudent use of the available resources for maximum output (Chertow, 2007; Akhtar et al., 2019). In response to these demands, the penchant for resource recovery and reuse are gaining recognition. The business and manufacturing sectors are displaying inclinations for resource sharing in order to maximize tangible benefits (Chiu and Yong, 2004a; Athanassiadis, 2016).

In this regard, IS helps to achieve the objective of industrial development without compromising the sustainability of environment. IS focuses on to reconfigure industrial activities in a way to minimize waste generation. The insights and innovative strategies help to re-utilize discarded industrial material at different stages of processing and production (Chertow, 2007). These tendencies are observable in the natural ecological systems. In these systems, the output of one component becomes the input for the other component. The exchanges of matter and energy in this way, thus, ensure the efficient use of resources without generating environmental pollution. The field of IS encourages such synergistic collaborations in the industrial activities to achieve the goal of environmental resilience. Therefore, industrial activities, based upon the principles of IS ensures that the industrial waste from one industry should be re-utilized by another unit as a raw material. In this way, the industrial symbiosis provides twofold benefits; on the one hand it reduces the cost of production and it also contribute in the protection of environment through pollution reduction (Nehm and Ulhøi, 2002; Yuan and Shi, 2009). However, the density, type and the nature of industrial activities suggestively influence the inclination for IS (Ruiz-Puente et al., 2014).

The term "industrial symbiosis" started to creep in the scientific literature during the recent years. Chertow (2007) elaborated the conceptual contours of the terminology by postulating a "3-2 heuristic minimum criterion". These benchmarks proved catalyst to distinguish industrial symbiosis from the other similar nature of waste exchanges and resource sharing mechanisms. According to this criterion, at least three different entities must collaborate for sharing two different resources, then, such an engagement can be termed as industrial symbiosis. Furthermore, the clarification rendered by Chertow (2007) also helped to crystalize the conceptual contours of IS. The elaboration visualized that such exchanges should involve traditionally different nature of companies. As compared to such assertions, the contemporary literature also include the synergistic collaborations within the similar entity. The proponent of this school of thought quote the examples of Guitang Group China (Zhu et al., 2007) and British Sugar (Short et al., 2014). In this connection, the postulations rendered by Yuan and Shi (2009) are also relevant. The researcher asserted that the symbiotic relationship in the industrial production may emerge as a result of exchanges between different units of a company.

The scholars such as Walls and Paquin (2015) elaborated the organizational theories of IS. They identified four different tiers; institutional level, network level, organizational level, and individual level of management. Similarly, the compartmentalization is also proposed and discussed from the following distinctive perspectives; intra-firm, inter-firm and regional engagement (Lowe, 2001). Yuan and Shi (2009) substantiated their assertion as a mean to explain and elaborate the intra and inter relationships in the industrial production.

The approaches associated with the IS were conceived on the following premises;

1) transforming wastes of one unit as an input for the other unit;
2) structural changes in the production line to abstract material commonly referred to as co-generation of material;
3) additions in the production line to improve the value of final products; and
4) up-gradation and capacity building enhance the efficiency.

Similarly, the difference in the views also prevails among the scholars regarding the classification of symbiotic relationships referred to as synergies. The most commonly used and referred classification by Van Beers (2007), categorizes such collaborations on the basis of their nature into the following three types:

1) ***By-product reuse***— the exchange of firm-specific materials between two or more parties as a substitute for commercial products or raw materials;
2) ***Utility/ infrastructure sharing***—the pooled use and management of commonly used resources such as energy, water etc.
3) ***Joint provision of services***—joint collaborations for mutual or ancillary objectives. The efforts including for fire suppression, improved transportation, and food provisioning (Chertow, 2007; Van Beers, 2007).

The notable examples based upon the assertions in classification have been summarize in Table 5.1.

Table 5.1:- Research articles on classification and categorization of synergies

Title	Reference	Classification Description
Industrial symbiosis opportunities for small and medium sized enterprises preliminary study in the Besaya region.	(Ruiz-Puente et al., 2014)	Mutualization and subitutions synergies
Classification of industrial symbiosis synergies: Application in the biofuels industry	(Martin et al., 2009)	Synergies are categorized on the basis of where the synergies originate and are destined to conclude.
Developing a classification system for regional resource synergies	(Golev and Corder, 2012)	Classification based on economic and environmental benefits
Industrial symbiosis literature and taxonomy	(Chertow, 2000)	Based on geographic proximity
Regional Synergies for sustainable resource processing A status report	(Bossilkov et al., 2005)	Provide three classification system i.e i)resource exchanges based, ii) processing and, iii) business relation governing the projects.
Industrial symbiosis and waste recovery in an Indian industrial area	(Bain et al., 2010a)	Based on geographic proximity

The case studies pertaining to the regional resource synergies also divulge that the evolution and management of such linkages are governed by the principles of “self-regulating” mechanisms. These bonds operate on the principle of conventional wisdom for cultivating financial benefits. Thus, the ensuing collaborations and resource sharing are, mostly, a product of intuitive drives. Therefore, the improved focus to insure systematic implementation of the framework is needed. Besides this, the desired capacity building regarding the selection of technology is also required. Bossilkov et al. (2005) endorsed such postulations. They hoped that the recent technological advancements and penchant for cleaner production will stimulate for calibrated collaborations in the industrial sector. The noted examples of regional synergy development at Kalundborg (Denmark), Kwinana and Gladstone (Australia), Kawasaki (Japan), Guitang (China), Ulsan (Korea) and Guayama (USA) also demonstrate the significance of such initiatives for economic development and cleaner environment (Ehrenfeld and Gertler, 1997; Van Berkel, 2006).

The findings (Table 5.1) based upon the review of literature, succinctly, portray the benefits of industrial symbiosis. These finding portray the multiple usages of waste products for diversified purposes. These collaborations in the industrial sector are inherently designed for the purpose of cost reduction and financial gains. However, these initiatives productively contribute towards resource conservation and pollution control. The findings based upon the surmise that the contributions from the small and medium enterprises (SMESs) have less acknowledgement as compared to large scale enterprises in this regard (Mir, 2008; Redmond et al., 2014). The role of the SMESs in this connection is more vital and critical for the financial and environmental health of the developing economies (Chattopadhyay et al., 2016).

Besides this, the findings also construe that the penchants for EID are in the industrial sector less observable among the developing economies as compared to developed regions. The lack of awareness, limited industrial based and inconsistencies in the policies regarding industrial and environmental issues are the observable barricades (Patricio et al., 2018). The situation necessitates for preventive and curative measures to ensure the environmental, economic and social resilience. It demands to quantify, treat, and focus on the industrial byproducts by plugging loops in the system (Chattopadhyay et al., 2016). In this connection, Van Beer (2009) advocated for synchronized efforts in the following spheres; I) awareness and capacity building, ii) acquisition of reliable data, iii) analysis and identification of doable synergy options, and iv) persistence/continuation in policies (van Beers et al., 2009).

In the present times, there is a growing realization that the approaches associated with IS are capable enough to yield dividends for the industrial and environmental sustainability. However, the differences in the opinions also prevail regarding the approaches; mechanics involved in the functioning; the nature of exchanges between different segments and the boundaries of the participating ‘entities. Thus, the contestation over the industrial symbiosis necessitate for scholastic initiatives to clarify the ambit of the “entity”. Therefore, the successful implementation of concepts pertaining to IS necessitated for comprehensive assessments based upon the contextual findings.

5.1.1. Industrial symbiosis in Pakistan

In Pakistan, SMEs constitute approximately 90% of all the enterprises; providing job opportunities to 80% of the non-agricultural labor force. Besides this, these contribute 40% in the Gross Domestic Product (GDP) of the country. However, these small enterprises are not in the focus of regulatory control. The reliable data is, almost, non-existent to affirm quality and quantity of waste generated by these SMEs in Pakistan. The reported revenue generation from salvages construe that there are potentials for resource recovery in Pakistan. However, the lack of orientation and neglect from stakeholders are the observable bottlenecks towards the efficient use of such resources. It is pertinent to mention that the research orientation towards IS is in the embryonic stages in Pakistan. The patronage for synergistic collaborations in the industrial sector is not vibrant in the country. The majority of such initiatives were led by the multinational firms at the facility or estate levels. The findings of these experimentations are available in the reports of the concerned organizations. The situation warrants for comprehensive assessments of the contextual potentials for improved productivity. The efforts will contribute towards the resilience of the natural/social environment. The realization of these objectives depends on coordinated efforts and out of the box postulations.

For the purpose, the implementation of strategies linked with the paradigm of CE seems to be a pragmatic option. The strategies associated with the CE offer the viable options to cultivate benefits without compromising over the integrity of natural environment. However, it requires the assessments of enabling factors, potentials and identification of key actors that can stimulate for such doable propositions. Thus, the present study aims at uncovering existing and potential synergies in the Industrial Estate of Islamabad. The study tries to identify the barricades towards business partnerships and synergies in this region.

Thus, the study will provide the baseline data for promoting EID in this region. It will have trickledown effects on SMEs. Therefore, the baseline assessments regarding existing resource synergies are vitally required, but, in short supply. These gaps are the missing links in a developing country such as- Pakistan. The present study will enable to postulate pragmatic frameworks for enhanced synergy linkages. It is hoped that the current study will serve as a catalyst to streamline the future course of actions. It will stimulate for synergistic collaborations among the industries of the study area. Besides this, the case study will also act as a precursor for the similar nature of research initiatives for promoting EID in Pakistan.

5.2. Results

The study reveals that out of 199 listed industrial units 155 entities are operative in the study area and only 117 are operating at their designated locations, the remaining 38 units have either halted their operation or have shifted their activities from the study area to ICT Model Industrial Zone, Islamabad. Nine (9) pharmaceutical industries were excluded from the list, as these units are in agreement with National Cleaner Production Center for waste treatment. Figure 3 portray the spatial distribution of the selected industrial units. The Figure construe that IEI is a diverse mix of SMEs operating within a smaller geographical vicinity. The complete inventory of the industries with requisite information such as the type of processes and location of these industry etc. have been condensed in the Appendix VII.

The analysis of the responses from different industrial units divulge that the term “industrial symbiosis” has not been well acknowledged among the respondents. Though, the industrial units are involved in various exchanges but the respondents are not acquainted with the concept of industrial symbiosis or industrial ecology. The findings revealed that the existing synergistic collaborations in the industrial sector are autogenously driven initiatives. These initiatives for cooperation are the products of intuitions. Therefore, the majority of such drives are conceived and executed without any formal framework, systematic arrangements or guidelines. The findings also transpire that out of 61 industrial units, which participated in this study, only 08 have dedicated staff with defined responsibilities for waste management, and only 5 are ISO 14001 certified. This situation reflects that the environmental protection and/or sustainable development are not a priority agenda for the management of these SMEs.

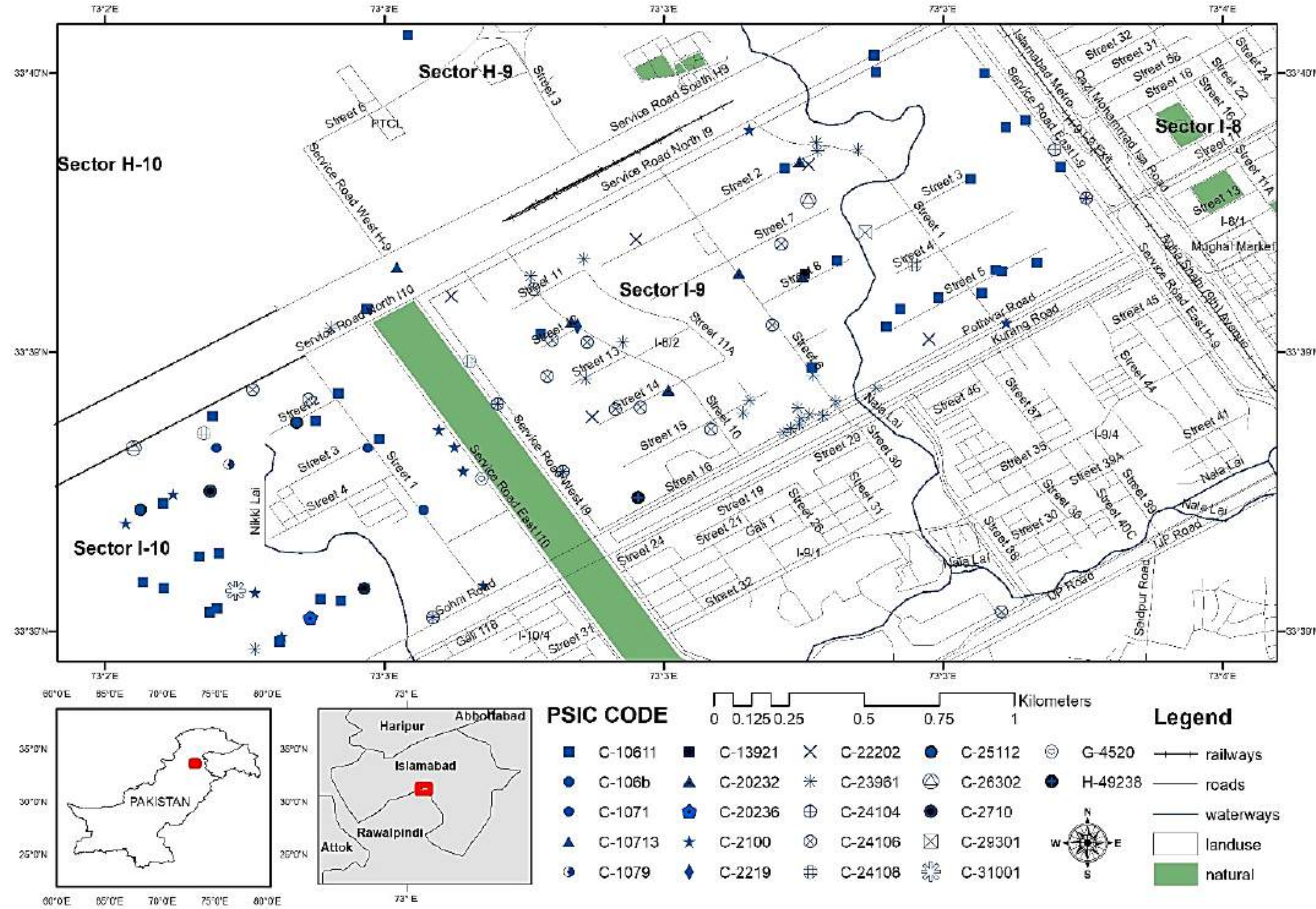


Figure 5.1. Spatial distribution and diversity of enterprises in the study area

5.2.1. Identified synergies

An inventory pertaining to existing synergies was prepared. The data obtained from 61 companies convey that the majority of the observed synergies are bilateral in nature. The list of the identified synergies and associated details have been summarized (Table 5.2). The findings in the Table 5.2 infer a minimum of 18 different types of by-product synergy collaborations.

Table 5.2. Identified byproduct exchange synergies

PSIC Code	Industrial Species	Major waste streams	Identified synergies
C-2396	Marble Processing	Marble dust/slurry Marble offcuts,	Marble offcuts utilized to make mosaics, engravings and floor chips.
C-24101	Basic Iron and Steel	Mill Scale, Slag, Air Filter Dust	Mill Scale reused in one unit while other sale to vendors for offsite utilization Air Filter Dust utilized by battery manufacturing company, Pharmaceutical Company and plastic manufacturing
C-24106	Structural Steel Products	Mill Scale Off cuts Waste oil	Mill Scale sold to vendors for offsite utilization Offcuts sold to scrap dealers which further sale it to steel furnace as scrap Waste oil is utilized as lubricant by automobile workshops
C-24108	Steel Pipe Industries	Scrap Matter Offcuts, Zinc, Hydrochloric Acid, Grease Oil	Scrap Matter and offcuts sold to dealers and re-utilized by steel furnace Hydrochloric Acid sold to market Zinc sold to pharmaceutical industry.
C-10611	Flour Processing	Wheat Chaff Rejected Grains	Wheat chaff & rejected grains are utilized for animal and poultry feed
C-10612	Rice Mills	Rice Bran	Rice bran is utilized for fish feed
C-22202	PVC Pipe Industry	PVC Resin	PVC Resin reused within industry
C-25112	Fabricated Metal Products	Plastic Waste (HDPE + PET) Offcuts	Offcuts sold to crap dealers and utilized by steel furnace
C-13921	Woolen Mills	Coarse fibers	Coarse fibers are utilized as fillers for quilts and furniture
C-10713	Baking industry	Food Waste	Food waste utilized as animal feed
C-31001	Furniture Industry	Saw Dust	Bedding for Poultry Farm to provide insulation.

The identified partnerships did not include the paper and packaging waste. Informal networks for the reuse and recycling exist for their byproducts. Besides this, none of the industry act as a receiver for this waste. However, the metal scrap was included in the assessment due to its volume and significance for the industrial operation in the region.

The findings amalgamate the diverse synergy collaborations of the study area into five distinctive groups. The categorization is on the basis of the physical characteristics of the materials being exchanged as: i) metal residues, ii) food residues, iii) plastics, iv) mineral solids, and v) others(which includes acids, lubricants, wool, PVC resin etc.).

5.2.2. Categorization of synergies

The present study evaluated the synergistic partnerships in term of spatial collaborations. The study compartmentalized the reported exchanges in the study into the four major categories:

1) Intra-firm exchanges
2) Inter-firm exchanges within IEI
3) Inter-firm exchanges outside IEI
4) Inter-firm exchange for co-product generation

5.2.2.1 Intra-firm exchanges

It refers to resource synergies within the generating facility. These types of exchanges envisage that the waste generated from one process is utilized in another process at the same facility (Bain et al., 2010b; Fraccascia et al., 2016). The byproducts of such exchanges do not leave the boundary of the generating facility. Table 5.3 provides the details of intra-firm exchanges taking place in the study area.

Table 5.3. Intra-firm exchanges

Type of Industrial Activity	Byproducts	Utilization
Marble Processing	Marble Offcuts	Utilized to produce engravings & mosaics
Steel Furnace	Slag	Utilized as road filler
	Mill Scale	Utilized in furnace to minimize carbon % in furnace
Re-rolling Mill	Waste Oil	2nd and 3rd class lubrication of spare parts
PVC Pipes manufacturing	PVC resin	Collected/ re-utilized in the process

5.2.2.2 Inter-firm exchanges within industrial estate

The industrial facilities located in the IEI also interact with each other. These unlike entities, in term of processing and production, collaborate with each other in a number of ways to achieve joint objectives. These entities hold meetings, forms associations and work as a co-suppliers for joint ventures. However, the propensity for such exchanges is not limited (Table 5.4).

Table 5.4. Inter-firm exchanges within industrial estate

Type of Industrial Activity	Byproducts	Synergistic Partner	Utilization
Steel Pipe Industry	Offcuts	Steel Furnace	Used as scrap for steel making
	Grease	Automobile Workshop	For lubrication
Structural Steel Products	Offcuts	Steel Furnace	Used as scrap for steel making
	Spent Oil	Automobile Workshop	For lubrication

5.2.1.3 Inter-firm exchanges outside IEI

Inter-firm exchanges are a peculiar type of interconnectedness. In this sort of collaboration, the byproducts of the industrial activities are exchanged with the partners located outside the study area. The researcher (Bain et al., 2010a) devised a criteria for the demarcation of geographical limits for such resource exchanges. The implementation of this criterion is difficult in our case due to the involvement of middle man. Table 5.5 sums up the details of the industrial wastes transported to various location for subsequent utilization.

Table 5.5. Inter-firm exchanges outside IEI

Type of Industrial Activity	Byproducts	Synergistic Partner	Utilization
Bakeries	Food Waste	Animal Farms	Utilized as animal feed at farmhouses in Islamabad
Rice polishing & finishing	Polishing Powder	Fishery Farms	Feed for fisheries in suburbs of Islamabad

Steel Furnace Dust	Air Filter Dust	Battery Manufacturing, Pharmaceutical Plastic	Metals extracted for cells outside Islamabad in Hattar Industrial Estate.
Steel Furnaces, Structural Steel Industry	Mill Scale		Sold to scrap dealers and transported to China

5.2.2.4 Interfirm exchange for co-product generation

It is a distinctive mechanism pertaining to synergistic relationship. In this special type of engagement, the byproducts generated at one facility are utilized at another processing unit by the same owner. These activities are integrated in order to provide raw material for the parent activity. This collaboration is derived from the natural ecosystem. These engagements ensure resource conservation and reduce environmental pollution. Table 5.6 portray and succinctly discusses the significant characteristics of the identified cases.

Table 5.6. Inter-firm exchange for co-product generation

Type of Industrial Activity	Byproducts	Co-product generation
Bakery	Food waste	One of the industries has developed an animal farm to provide meat for bakery items. Food waste generated from bakery is utilized as feed for that animal farm.
Steel Furnace and Structural Steel	Offcuts	Offcuts produced during rolling process of steel are re-melted in furnace. In one case, furnace is located in Lahore while rolling mill in Islamabad. Offcuts are transported to Lahore to be recycled.

5.2.3. Key enablers and barriers

The findings revealed that 80% of the solid byproducts from industrial activities are exchanged and recycled. The survey of industries and meetings with the stakeholders helped to construe about the key enablers;

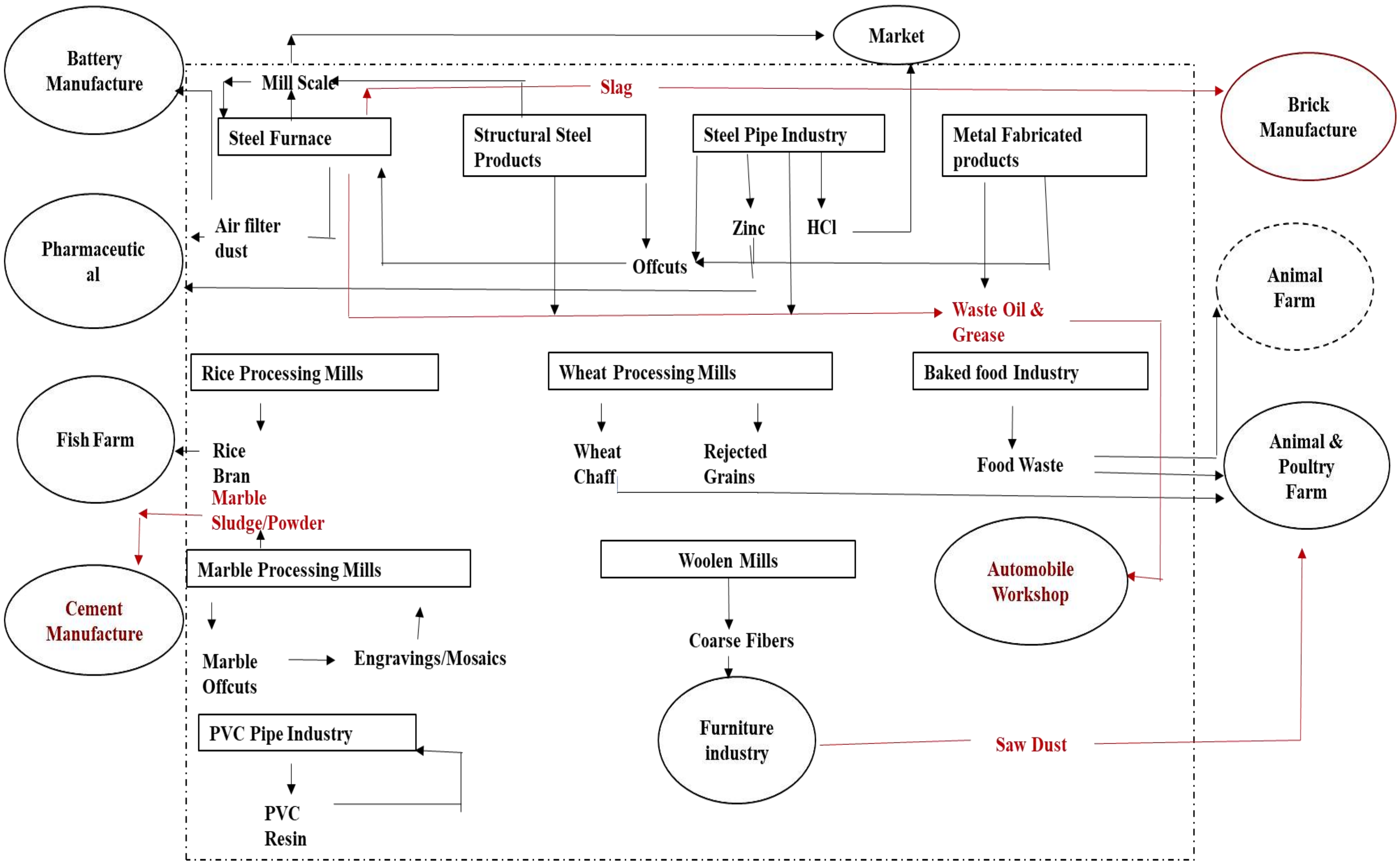
- Cost differences between virgin raw material and the material salvaged from byproducts.
- Presence of potential partners to assure continuous supply of material.

- Presence of a flexible or non-stringent regulatory regime for waste utilization.

While the barriers identified include;

- Oscillations in the supply of material, as most of the SMEs operate in batch wise manner.
- Fluctuating prices of the materials due to the over-arching role of the middleman.
- Little or no regulatory fees on the dumping of industrial waste. It makes the synergies less attractive option particularly in the cases where price differences between the virgin material and byproducts are not marked.
- Non-availability of the platform for the dissemination of knowledge/information to facilitate the desired exchanges.

It was also concluded that the inclination for the collaborative partnerships are not encouraging in the vicinity. Industries are either not aware about the quantities of the waste produced at their facilities or ignorant about its potential usages. Besides this, they are even reluctant to share such information. The identified and potential synergies have been cartographically illustrated (Figure 5.2).



Circles: Consumers; Rectangles: Producers; Black color: Existing synergies; Red Color: Potential Synergies

Figure 5.2. Byproduct exchange synergies at IEI: Producers and Consumers

5.2.4 Examples of existing by-product synergies

5.2.4.1 Marble offcuts

There are 21 units for marble processing and polishing in the study area. The number of employees engage for the production vary from 06 to 20, thus, these units are classified as small-scale enterprises. During the processing, the small irregular fragments of marble referred to as offcuts are produced. The findings constitute that 5 to 8% of the total processed marble goes in the form of offcuts. Thus, the processing in these units produced approximately 1500 to 1800 tonnes annually of discarded industrial waste. The greater proportion of very small sized offcuts are used in the construction industry as floor chips. While, the offcuts of precious stones are reprocessed to produce mosaics and engravings for decoration purposes.

5.2.4.2 Mill scale

Mill scale, known as scale or flakes, is a byproduct produced during the process of rolling in the steel mills. Mill scale mainly consists of the oxides of iron. Mill scale has a variety of reported usages (Umadevi et al., 2009). The byproduct is used in the cement klinker production (Young and Norris, 2004) and for preparing iron powder (Benchiheub et al., 2010). The findings of the study infer that the major share of the mill scale is sold to vendors. These vendors, export this mill scale to China. While, there is only one industrial unit in the study area, that process the mill scale. Approximately, 690 tonnes of mill scale is annually produced in this facility. The processed mill scale is reutilized to substitute raw material.

5.2.4.3 Air filter dust

The electrostatic precipitators installed in the steel furnaces collect particulate matters known as “Air Filter Dust (ADF)”. The dust is subsequently collected. It is mainly composed of the oxides of metal with a high concentration of Zn, Pb and Fe. The constituents of the ADF are used as a raw material for manufacturing pigments, cells and batteries. This industrial waste also has a productive value for the pharmaceutical industry. The quantities of ADF produced differ from 0.5% to 0.8%. The fluctuations in the quality and quantity of the dust is dependent on the raw material (scrap), the technology used for the processing and quantum of the steel produced. The findings reflect that approximately 1550 tonnes of the ADF is annually produced in the study area. The statistics indicate that the collected ADF is channelized through different conduits. One of the industrial unit affirmed that they shift it to pharmaceutical industry where the Zn is extracted from the dust. The second company is selling it to battery manufacturing unit. While, the third consumer of this byproduct is the plastic manufacturing industry.

5.2.4.4 Metal offcuts

The metal offcuts are the small pieces of steel, produced during the cutting of billets, iron rods, T-irons and other metallic products. The estimates suggest that approximately, 10,000 to 15,000 tonnes of such offcuts are produced every year in the study area. These redundant pieces of metal and steel are purchased by the scrap dealers and sold to steel furnaces. There are only 04 industrial units equipped with the facilities to consume this byproduct. These facilities re-utilize these metallic offcuts and other industrial waste in the furnaces.

5.2.4.5 Zinc

Zinc is used during the process of galvanization in the steel pipe industry. During these procedures a powdery substance mainly composed of the Zinc is produced. That Zinc powder is recovered and sold to pharmaceutical industry. Approximately, 4000 tonnes of zinc powder is retrieved annually and vended as a byproduct in the market every year.

5.2.4.6 Hydrochloric Acid

Hydrochloric acid is also used in the iron and steel industry. The acid is required during the galvanization process for manufacturing galvanized iron pipes. The acid is recollected after the procedures, and impurities removed/reduced before hydrochloric acid is reused. It is sold in the market for subsequent use.

5.2.4.7 Wheat chaff and rejected grains

There are 36 wheat processing units in the study area. Wheat chaff, is the husk that covers the wheat grains. It is removed during and after the crushing process. Wheat chaff have a very high nutrient value but are indigestible for the human. While, the byproduct is very beneficial for the cattle. Therefore, the wheat chaff is sold to animal farms. The byproduct is used as a food supplement for the livestock. Besides this, a substantial proportion of very small sized rejected grains from these wheat processing units is, also, sold and utilized in the poultry feed.

5.2.4.8 Rice bran

Pakistan is famous for its quality rice in the world but it is not cultivated in the study area. The rice processing is carried out in two different levels prior to marketing. At the first level, the de-husking of rice is carried out and rice is stored for at least two to three weeks. Then, the rice from de-husking unit is transferred to polishing unit. Polishing is the process of cleaning and polishing of brown rice. The procedures are applied to produce different value-added products like silky and non-silky rice. The polishing is carried out by different techniques. This process produces two types of byproducts i.e. broken rice and rice bran. Broken rice in Pakistan is consumed as a food and sold in the domestic market. Therefore, the broken rice is treated as a co-product of the process. While, the rice bran that constitutes about 8-10% of the total production, is used as a food for the fish. In the study area there is a rice-polishing unit. The unprocessed rice is brought in the processing facility for intermediary procedures before its polishing. The waste (rice bran) is sold to local fish farms as a byproduct.

5.2.4.9 Polyvinyl Chloride Resin

There are five polyvinyl chloride (PVC) pipe manufacturing units in the study area. One of the main ingredient for PVC pipe manufacturing is PVC resin. A small amount of the PVC resin is collected as industrial waste and reutilized in the process. In-situ utilization yields the dividends in three forms; reduces pressure on the resources, contribute towards waste reduction and produce financial benefits. Thus, the reutilization of the (PVC) resin is a productive contribution from the industrial sector of the study area.

5.2.4.10 Old wool

There are two woolen mills in the study area. Both of these, are of small sized (less than 20 employees) enterprises. These industries work in batch-wise manner. The finest and softest wool fibers are used for knitwear production, while, the coarse fibers (old wool) are rejected. The rejected stuff is sold to furniture industry. The recipient industry utilize this discarded material for the filling purposes. The rejected stuff is also consumed for quilt making as well. The findings of the study portray that the discarded coarser fiber approximately constitute 3% of the total processed wool.

5.2.4.11 Food waste

Food waste is a global concern. A substantial amount of food waste is generated during the food processing activities and could be utilized as animal feed (Griffin et al., 2009). There are two baking units in the study area. The food waste from these units is mainly comprises over the rejected baked items and ingredients. This food waste is utilized as the animal feed. One of these baking unit sale their waste to local livestock keepers, while, the other use it in their animal farm. The dairy farm is a subsidiary of that food processing units and the food waste is used as animal feed. The farm provides milk and meat for the bakery products. Thus, the circulatory flow of the food waste is productively contributing towards the economic activities and environmental resilience.

5.2.5 Identified future potential synergies

There are promising prospects for the following industrial byproducts on the short-term basis in the study area.

5.2.5.1 Slag

Slag is a glass like industrial byproduct. It is generated from the steel furnace after the metal extraction. Slag is mainly composed of metal oxides and silicon oxides (Shen and Forssberg, 2003). We estimate that approximately 20,000 tonnes of the slag is produced annually in the study area. The quantity varies and dependent upon the characteristics of batch wise production. This slag is currently utilized for filling the pits or utilized for leveling the land surfaces. However, the studies affirm that the slag can be consumed in brick making (Mohammed et al., 2017; Ahmad and Rahman, 2018; Ma et al., 2019).

5.2.5.2.Waste oil and grease

The natural/synthetic oil and greases are used for machine lubrication. The lubrication is profusely applied during the rolling process in the industries such as those producing metal products and steel pipe etc. The unused lubricants are wasted along with the waste water. However, the discarded oil and grease are also collected, processed and reused for various purposes. Therefore, the discarded industrial effluent from these units have a potential for the local automobile sector. The collected liquid after processing can be reused for cleaning and lubrication of auto-parts. The neglect is a dangerous proposition for the aquifer of the study area. Thus, the synergistic collaborations are also incumbent for the protection of water resources in this area.

5.2.5.3 Marble sludge

Marble processing units significantly contribute in the construction industry. During the polishing and grinding of marble, a large amount of sludge is produced due to the mixing of marble dust with the water. This sludge is collected and disposed of as redundant industrial waste. The disposal on open land areas causes soil and land degradation. The recent scientific advancements in the material sciences have postulated the measures and methods for ensuring productive use of the sludge in the cement making processes (Topal et al., 2006; El-Sayed et al., 2018). Besides this, the waste sludge can productively contribute up to 9% as an additive material in the cement production.

5.2.5.4 Saw dust

Saw dust is a byproduct of the timber industry. It is mainly produced when the wood is cut or processed for the finishing purposes. The saw dust is produced in the study area during the constructional activities and furniture making. The saw dust is primarily used as a bedding material in the poultry farms due to its insulating characteristics. However, the low income groups in the study area also used the saw dust for the heating/ cooking purposes. The exact quantity of the saw dust produced in the reported industrial units is a matter of conjectures. The volume of the byproduct significant oscillate and highly dependent on the business of the furniture industries. Besides this, the quantifications and estimations are more problematic and yield unrealistic results in the undocumented economies such as Pakistan.

5.3 Discussion

One of the main objective of the current investigation was to identify the nature of linkages in the industrial activities of the study area. The assessment of prevalent associations and partnerships is required to construe the future prospects of such collaborations. These understanding are needed for improving the contribution of industrial sector towards the sustainable development. The findings of similar studies also stress on such scholastic initiatives. These drives are incumbent to ensure eco-friendly industrial development (Bossilkov et al., 2005; Chertow, 2007; Martin and Eklund, 2011)

In this connection, Costa et al. (2010), Gibbs and Deutz (2005) and Tao et al. (2018) are convinced that the postulations based upon empirical findings are more relevant than laboratory driven paradigms. Consequently, the use and reliance on the contextual information should get more focus and weightage during the formulation of policies and devising regulatory frameworks. These orientations are incumbent to achieve the goals enshrined in the “triple bottom lines”.

For the purpose, the information was retrieved from the industrial enterprises operating within the administrative jurisdiction of Islamabad Capital Territory (ICT). The data was obtained through field investigation and mapped (Figure 4.3). The critical findings portray that the majority of the inhabitants are engaged with the tertiary economic activities (services); followed by the secondary economic activities (manufacturing or production etc.) sectors. The majority of these employees are associated with the public or private sector for earning their livelihood. The inclination for self-employment is an insignificant feature in the study area.

GIS based maps and assessments helped to identify complementary byproducts in the study area. GIS mapping significantly contributed in the spatial assessments. GIS based techniques enabled to decipher the ensuing impacts of symbiotic linkages on the environment and socio-economic stability of the study area. GIS based findings also helped to decipher options for ensuring resource conservation through collaborations.

The findings portrayed that the majority of the industrial activities in this region belong to the category of the SMEs. These enterprises are diverse in nature but co-located in the sense of spatial distribution (Figure 5.1). These characteristics such as the functional diversity and geographical proximity, offer a conducive contextual settings for promoting regional resource synergies (Chertow, 2007; Jensen, 2016). Therefore, the eco-industrial growth may gain momentum with the operationalization of the ICT Model Industrial Zone, Islamabad (Abid and Ashfaq, 2015). That facility for promoting industrial development is being shaped under the aegis of CPEC. The emerging scenario demands for coordinated efforts from academics and researchers to substantiate efforts intended for structural readjustments of the economy CPEC.

However, the classification of industrial activities in the context of a newly industrializing region, is a foremost challenge. The availability/acquisition of the statistical data in the required format is also problematic. The acquisition of such critical information are incumbent for the identification, categorization and assessments pertaining to synergies. Therefore, the classification scheme proposed by PSIC was adopted as a benchmark. The scheme offer a coherent and consistent mechanism for classification and assessments. It is based on a set of internationally agreed concepts, definitions, principles and classification rules. The scheme was adjudged appropriate and fulfill the needs for such investigations in the contextual settings of Pakistan (GoP, 2010). Besides this, the format of it enables to organize the detailed information according to the principles of economics and industrial ecology (Kincaid and Overcash, 2001; GoP, 2010). Therefore, the findings provide the baseline data and conceptual framework for stimulating EID in Pakistan. The identification of key enablers and barriers are also pertinent for planning to enhance synergistic collaborations in the industrial sector of this region.

The study divulge that the quantification of byproducts is a real challenge for the policy maker and researcher in the undocumented economies. The situation is further complicated because majority of these SMEs operate in batch wise fashion. Thus, the continuous availability and estimation of amounts becomes problematic and unrealistic. It is evident from the example of rice bran (Table 4.3). Thus, the abnormal fluctuations in the production poses serious questions about the reliability and validity of estimations.

The population of the study area is rapidly increasing (Ali and Malik, 2011; Khwaja, 2012; Atif et al., 2018a; Bokhari et al., 2018). The unprecedented urbanization in the study area is exerting pressures on the natural and human resources (Ali and Malik, 2011; Butt et al., 2012; Atif et al., 2018a; Bokhari et al., 2018). However, the industrialization is the only viable option for these developing regions to accommodate the growing pressure for the job and demands for human survival. Therefore, the synergistic collaborations in the industrial sector are mandatory for resource conservation and pollution reduction. Thus, the prudent use of industrial waste is a pragmatic avenue to ensure resource conservation and environmental protection.

The findings also formulate that the study area is a hub of diverse types of SMEs. These SMEs are mainly operating in the four types of processing domains. The prominent industrial activities are the flour mills (30.7%); marble processing units (18%); steel and fabricated metal units (16%), and pharmaceutical products (7.6%). Whereas, the waste generated from pharmaceutical industries is incinerated by the National Cleaner Production Center (NCPC) and wastewater is discharged in the streams. It is causing ground and surface water pollution in the study area. The situation necessitate for actions to protect the aquifer. The reported population growth, urbanization and industrialization will exacerbate the situation. Hence, stringent regulatory control and efficient monitoring are required to address the looming challenges.

There are proclivities for byproducts exchanges in the industrial sector. The reported assessments infer that the maximum benefits can be retrieved through industrial collaborations. These benefits have more acknowledgements in the study area among the processes associated with metal fabrication and structural steel products etc. However, the critical findings of the study also formulate that the industrial symbiosis is not currently a much penetrated concept among the stakeholders. It helped to interpret that the majority of the synergies/symbiotic collaborations in the study area are autogenously structured relationships. The observed partnerships for collaborations evolved without any systematic effort. While, the study area have potentials for more promising synergistic partnerships.

5.4 Conclusion

T Though, the stakeholders are not aware about the conceptual paradigm of industrial symbiosis, yet, they are inclined for such collaborative partnerships. The assessments identified the monetary gains and eco-friendly regulations as key enablers to promote existing synergies. The study suggests that loosely defined mechanism between the partner, price control by the middle man and lack of information about the byproducts are the visible barriers for the synergistic collaboration. Future research pertaining to quantification of waste materials and for curtailing the role of the middle man are needed.

CHAPTER 06

ENVIRONMENTAL AND ECONOMIC BENEFITS ARISING FROM INDUSTRIAL SYMBIOSIS

CHAPTER- 6

ENVIRONMENTAL AND ECONOMIC BENEFITS OF INDUSTRIAL SYMBIOSIS

6.1. Introduction

Human extract, process and relocate substances and materials from the surface of the earth. The associated activities are obligatory for the human survival and progression. However, the redundant materials from the manufacturing and industrial sectors are stressing on the natural and social environments. The ensuing complications and imbalances for the environment and its resources are exacerbating. The consequential impacts for human and natural environment necessitate for integrated responses.

The contemporary situation entails for conclusive assessments of contextual needs pertaining to natural resources. These initiatives are needed to achieve objectives of sustainable development. The understandings are mandatory to convert the ensuing challenges from anthropogenic activities into opportunities. The identification of such prospects is obligatory for conservation of resources and protection of environment. For this purpose, holistic appraisals and coordinated management of human activities are incumbent. Therefore, the research inclinations are more skewed in favor of "out of the box" postulations.

In this context, industrial symbiosis (IS) is being recognized to substantiate such efforts. The conceptual contours of IS are embedded in the philosophy of mutualistic benefits through integration of interests (Chertow & Lombardi, 2005). The approaches and mechanisms associated with the IS and Circular Economy (CE) envisage that the industrial and manufacturing sectors should deliberate beyond the sectorial and monetary interests. The embedded inclinations of IS and CE also encourage technological innovation and human resource development for improved productivity. Thus, the frameworks of IS and CE aim to accomplish the targets of social, economic and ecological resilienc

The IS supports synergistic collaborations through exchanges of waste material and energy among in an industrial system. The resultant linkages and integrations reduce pressures on the natural resources and energy inputs. Consequently, the waste production is minimized and emissions are curtailed. These mechanics of the IS are rooted in the operational principles of the natural system. The natural systems operate on the premises that the output of a component is a resource for the succeeding constituent in the hierarchy. It ensures the efficient use of resources and eliminate the waste from the natural environment. The techniques and measures affiliated with the IS and CE also envisage such benefits for the producer and consumer (Chertow and Lombardi, 2005; Jacobsen, 2006). Thus, the challenges for the natural environment and accompanying opportunities offer by the paradigm of IS are imparting interests for CE (Chertow, 2000). The quest for such inclinations increased during the previous decades (Sterr and Ott, 2004). The literature pertaining to numerous dimensions of IS multiplied during the past 10 to 15 years (Chertow, 2000; Yu et al., 2014). However, the required focus to decipher the impacts of industrial activities on the natural and socio-economic landscapes is, still, in the nascent stages (Martin et al., 2015; Akhtar et al., 2019). The research regarding IS and CE are more skewed in favor of descriptive assessments. Besides this, these research initiatives are mostly anglicized from conceptual considerations. The recent formulate that the more focus is needed in IS research towards quantitative assessments based upon empirical data (Martin et al., 2015).

For the purpose, the literature related to IS was surveyed. The investigation particularly evaluates the embedded orientations of contemporary research. The findings based upon the content analysis have been condensed in Table 6.1. These quantitative assessments helped to construe about the potential benefits associated with the IS. These scholastic initiatives are stimulating a quest for IS, as a pragmatic framework, for the sustainability of economy and environment (Dong et al., 2013b).

Table 6.1. The reported environmental and economic benefits of resource

Case Study (Reference)	**Benefit**	**Quantification**
Kalunborg, Denmark (Chertow and Lombardi, 2005)	Ground water savings	2.1 million m^3 per year
	Surface water savings	1.2 million m^3 per year
	Oil savings	20,000 tonnes per year
	Natural gypsum	200,000 tonnes per year
Wyeth-AES Guayama water exchange (Chertow and Lombardi, 2005)	Amount of water exchanged AES Guayama savings	92.4 million gallons per year
	Avoided cost,	$184,800 per year
	Avoided cost, cooling water use	$18,480 per year
	Avoided cost, boiler makeup use	$92,400 per year
Liuzhou Iron and Steel, China (Dong et al., 2013b)	1.2 MT of BF Slag exchanged with cement plant	<u>For Iron and Steel Industry</u> Conserve electricity 136 M KWh/y, Reduce slag stock-pilling 1.2 Mt/y Sales income 35.96 M USD Avoid cost 16.23 MUSD <u>For Cement Plant</u> Substitute clinker 1.2 Mt/y Avoid cost 3.51 MUSD
	Desulfurization by-product 8100 ton/y sold to chemical plant	Reduce SO_2 4 kt/y, For iron/steel, Sales income 0.73 MUSD Avoid cost 0.74 MUSD
Jinan Iron and Steel, China (Dong et al., 2013b)	1.8 M tonnes per year of BF slag exchanges with cement plant	Save raw material of cement. Sales income 10.37 M USD Reduce slag stock-pilling 180 Mt/y.
	1.2 million tonnes of steel slag per year exchanged with cement plant	ave raw material of construction and sinter ore. 85.2 MCNY/y (12.28 M USD) Reduce stock-pilling 1.2 Mt/y.
Kawasaki, Japan (Dong et al., 2013b)	1.6 million tonnes per year of red mud sold to iron and steel industry by aluminum	Extracted iron ore power 450 kt/y. Avoid cost 41.11 M USD Reduce red mud stock-pilling 1.6 Mt/y.
	65 kilo tonnes per year of steam produced by iron and steel exchanged with chemical plant	Save fuels of ammonia production.
	10 kilo tonnes per year of Gypsum produced by iron and steel industry is exchanges with cement plant	Save raw material of construction industry.
	120 kilo tonnes per year of chromium slag produced by chromium chemical exchanged with iron and steel industry	Save sinter ore 120 kt/y. Avoid cost 12.10 M USD Reduce chromium slag stock-pilling.
	2 million tonnes of urban waste water utilized in iron and steel industry	

In the reported studies (Table 6.1), the environmental and monetary benefits of IS were quantified. The studies tried to quantify the various contributions from cycling of materials and energy. These scholarships are more inclined to assess the financial dividends through waste reductions. The findings transpire that the participating entities in IS secure rewards in the form of reduced transport charges and get inputs on discounted rates. Besides this, the intangible benefits such as improved reputation and support in the market are secured through such exchanges. However, the quantum of these benefits is dependent on the nature of processing, and quantity of the materials being exchanged etc.

6.1.1. Industrial symbiosis in Iron and Steel industry

The iron and steel industry plays a pivotal role in the process of industrialization. The trickle down effects from the steel industry significantly contribute in the economic stability. The steel is among the most widely used metals and its requirements are increasing (Zhang et al., 2013b). Therefore, the sector is expanding at an impressive speed and scale across the world. The world steel production increased at an astounding rate of 5.3% (Arens et al., 2017) and production was adjudged 1.6 billion tonnes during the year 2017 (Özdemir et al., 2018).

The reported expansions, growth and restructuring of economies in the developing countries are offering new found opportunities and challenges for this sector. The desired infrastructural developments are significantly dependent on the efficiency of iron and steel industry. Regrettably, the performance of this industrial sector in Pakistan is not appreciable. The reported findings formulated that the annual steel demand in Pakistan is 7.1 Tg with per capita utilization of 37.5 kg. The domestic steel industry is producing 3 to 4 Tg of steel and the resultant shortfall is bridged through imported steel (Khan et al., 2011).

The process of steel production is subdivided in two major groups. The subdivision is based upon the types of the raw material being utilized. For the purpose, the processed iron ore or recycled metal scrap are used the formulation of steel with the help of virgin iron ore is an energy intensive industrial activity. The procedure is carried out in the blast furnaces, basic oxygen furnaces and open hearth furnaces. Whereas, the use of recycled metal scrap is inherently energy efficient process as compared to the first option. The required procedures with the scrap are executed in the Electric Arc Furnace (EAF) or in an Induction Melting Furnace (IMF) (Özdemir et al., 2017).

The iron and steel industry is an energy intensive sector (Zhang et al., 2013b; Olmez et al., 2016) and adversely impact the environment (Burchart-Korol, 2013; Dong et al., 2013b; Arens et al., 2017). The sector is adding up a very significant amount of CO_2 emissions (0.59 Tg) in Pakistan. It is approximately 3% of the total Greenhouse Gases

(GHGs) emissions of the country (Khan et al., 2011). The ensuing scenario warrants for integrated responses as enshrined in the paradigm of Life Cycle Assessments (LCA) (Burchart-Korol, 2013; Olmez et al., 2016; Özdemir et al., 2017).

The current study was designed to assess the orientations in the research pertaining to the conceptual paradigm of LCA. Table 6.2 summarized the qualitative findings of the studies carried out by adopting the framework of LCA. These scholastic initiatives were primarily conceived to evaluate the economic and environmental impacts of iron and steel industry.

Table 6.2. Life Cycle Assessment studies in iron and steel industry

Reference	Region	Furnace type	Impacts studied	LCA tool used
(Olmez et al., 2016)	Turkey	Blast furnace/basic Oxygen Furnace	Human Health and climate change	Simapro
(Burchart-Korol, 2013)	Poland	Blast Furnace and Electric Arc Furnace	Fuel consumption and greenhouse gas emissions	Simapro
(Özdemir et al., 2018)	Turkey	Induction Melting Furnace	Abiotic depletion, global warming, ozone layer depletion, Human toxicity, aquatic toxicity acidification, eutrophication, photochemical oxidation	Simapro
(Chen et al., 2011)	China	BOF	Global warming potential	
(Li et al., 2016)	China	BF	CO_2 emissions	EIO-LCA

The findings infer that the majority of assessments are based on the information retrieved from the blast furnace or EAF (Table 6.2). These investigations also focused on the raw material used for the steel production. The findings divulge that the reliance on the metal scrap as raw material in the IMF is more prevalent in Pakistan. Therefore, the current study was designed to triangulate the impacts of waste exchanges through IMF. The appraisals will help to determine the monetary benefits of such collaborations for the iron and steel industry and associated partners. Therefore, the study compared two hypothetical production scenarios i) linear flow production, and second, ii) closed loop production approaches.

6.2. Results

There are two kinds of steel producing activities in the study area; 1) steel and re-rolling mills, and 2) rolling units. In the first type of industrial units, the iron scrap is used as an inputs. These units are fabricating steel billets and rebars. These units are also producing slag, mill scale, refractories, air filter dust and off cuts as byproducts. While, in the second type of entities the steel billets are used as input for manufacturing mill scale. For the purpose, the process is carried out in two stages. In the first stage, the steel billets are produced by melting the scrap in the induction furnaces. The semi-finished product, steel billets, are molded to produce steel rebars, T-iron and wires etc.

6.2.1. The waste diversion from landfill

Different types of industrial waste is generated during the production process. In the first stage, by-products such as slag, refractories, mill scale and air filter dust are generated. These are exchanged with partner industries. While in the second stage, the mill scale, rolling waste and offcuts are discarded as industrial waste. The major proportion of such byproducts are recycled except refractories and slag. The resultant byproducts are further processed within the similar industrial facility or sold. Thus, these intra-firm and inter-firm exchanges are productively contributing towards resource conservations. These symbiotic interconnections are approximately diverting 47 kg per tonne of production from landfills to productive use. However, a significant share such as 75 kg of slag refractories and coal waste are either disposed of or reused as road filler. Thus, the waste is utilized in lieu of virgin material within the facility or sold out to generate revenue. Therefore, these synergistic partnerships are transforming the industrial waste for productive use. The significant findings of the study regarding the potential amount of byproducts produced per unit of final steel product (functional unit) has been summarized (Table 6.3).

Table 6.3. Types and amount of byproducts produced per unit of production

Types of byproducts	Utilization	Amount generated per unit of production
Slag	Disposed off/road filler	45 Kg
Refractories	Disposed off	35 kg
Mill Scale	Induction melting furnace as oxygen source	20 kg
Offcuts	Re-melted in Furnace. Rolling unit sale it to furnaces	10 kg
Rolling Waste (wires)	Re-melted in furnace or Purchased by mini wire mills	07 kg

Air Filter Dust	Purchased by plastic manufacturing or battery manufacturing companies	10 kg
Coal Waste	Disposed off	25kg

6.2.2. Revenue generation through byproduct exchanges

The assessments rendered that the byproducts exchanges have utilitarian value and potentials for revenue generation. The table 6.4 enlist the prices at which the byproducts/scrap is traded. Whereas, the reported prices are highly subjective to market drivers, yet, give an idea about the prospects of income generation from the industrial waste.

Table 6.4. ***Revenue from sale of byproducts***

Types of byproducts	Quantity per unit production	Earnings per tons of steel production (in Rs)
Mill Scale	20 kg	30
Air Filter Dust	10 kg	30
Cutting ends	10 kg	700
Rolling waste	7 kg	504
Total		**1207**

The findings also construe about a revenue generation through exchanges of slag and refractories. These byproducts are currently disposed of within or outside the industrial units.

6.2.3. CO_2 emissions

6.2.3.1 Linear production process

The findings pertaining to the life cycle inventory of steel billets and steel rebar production have been summarized in (Table 6.5) and (Table 6.6). The electricity for the production process is supplied through grid distribution. While, the water requirements are cater through the ground and surface water resources. However, the water is recycled several times, within these premises and discharged as industrial waste water. The statistics concerning to atmospheric emissions were sieved from the compliance reports of these industries. The cost on logistics pertaining to raw material transportation and incurred on product delivery were excluded from the estimations.

Table 6.5. Life cycle inventory of 1-tonne of steel billet production

Input and output	**Units**	**Amount**
Iron Scrap	Kg/t	1080
Ferrosilicon	Kg/t	03
Ferro-manganese	Kg/t	10
Carbon Black	Kg/t	02
Flourspar	Kg/t	02
Silica-lining	Kg/t	35
Liquid Oxygen	Kg/t	03
Electricity	Kwh/t	600
Surface Water	Kg/t	08
Outputs		
Emissions to Air		
CO_2	Kg/t	5.5
CO	Kg/t	0.516
NO	Kg/t	0.026
NO_2	Kg/t	0.187
Dust	Kg/t	0.043
Volatile organic compounds	Kg/t	0.001
Lead	Kg/t	0.00085
Cadmium	Kg/t	0.00003
Zinc	Kg/t	0.00651
Nickel	Kg/t	0.00001
Chromium	Kg/t	0.00003
Final Waste Flows		
Slag	Kg/t	45
Refractories	Kg/t	35
Air Filter Dust	Kg/t	10
Mill Scale	Kg/t	10

Table 6.6. Life cycle inventory of one tonne of steel rebar production

Input and output	Units	Amount
Inputs		
Steel Billets	kg/t	1,030
Electricity	kWh/t	73
Coal	Kg/t	96
Groundwater	Kg/t	32
Outputs		
Emission to Air		
CO_2	Kg/t	3.7
CO	Kg/t	0.037
SO_2	Kg/t	0.0039
NO	Kg/t	0.179
NO_2	Kg/t	0.267
Dust	Kg/t	0.0005
Final Waste Flows		
Mill Scale	Kg/t	10
Rolling Waste (wires)	Kg/t	7
Offcuts	Kg/t	10
Coal Waste	Kg/t	25

Figure 6.1 portray process flow diagram of a typical induction melting furnace in the study area through linear process. The figure 6.1 conclusively illustrate the inputs and processes involved in steel rebar manufacturing. The total emissions from this linear flow process is 546 kg CO_2 eq/t. The findings formulate that the steel billet production significantly contribute (88.5%) in the Greenhouse Gases (GHG) emissions. The statistics infer that approximately 499 kg CO_2 eq/t of emission is contributed by such processes in the environment. The emission from electricity consumption was observed 330 kg CO_2 eq/t. The Sankey diagram (Figure 6.2) portray the emissions characterization based upon the estimations of 1 ton of steel rebar production.

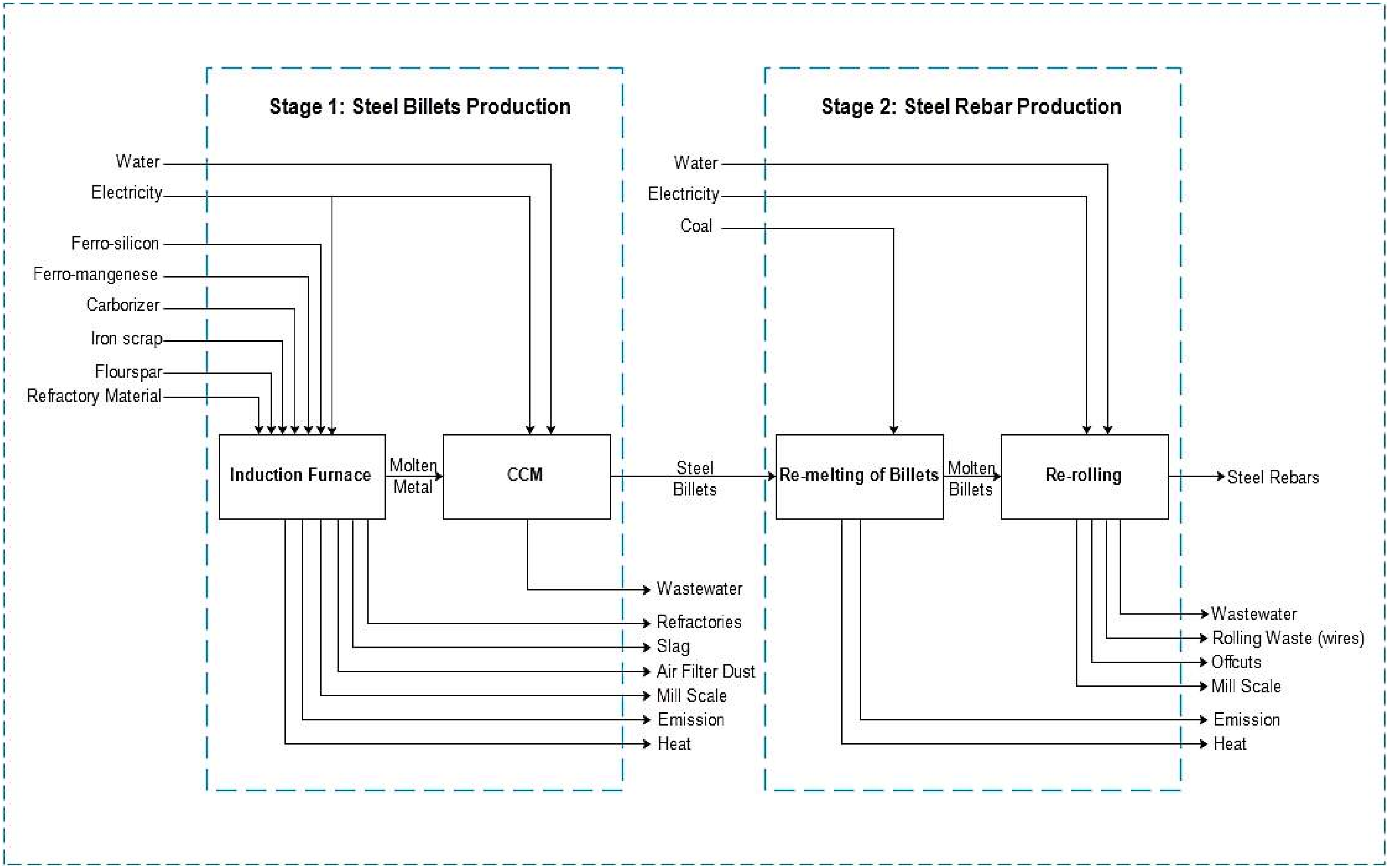


Figure 6.1. Scenario I- Linear process flow diagram of steel rebar production

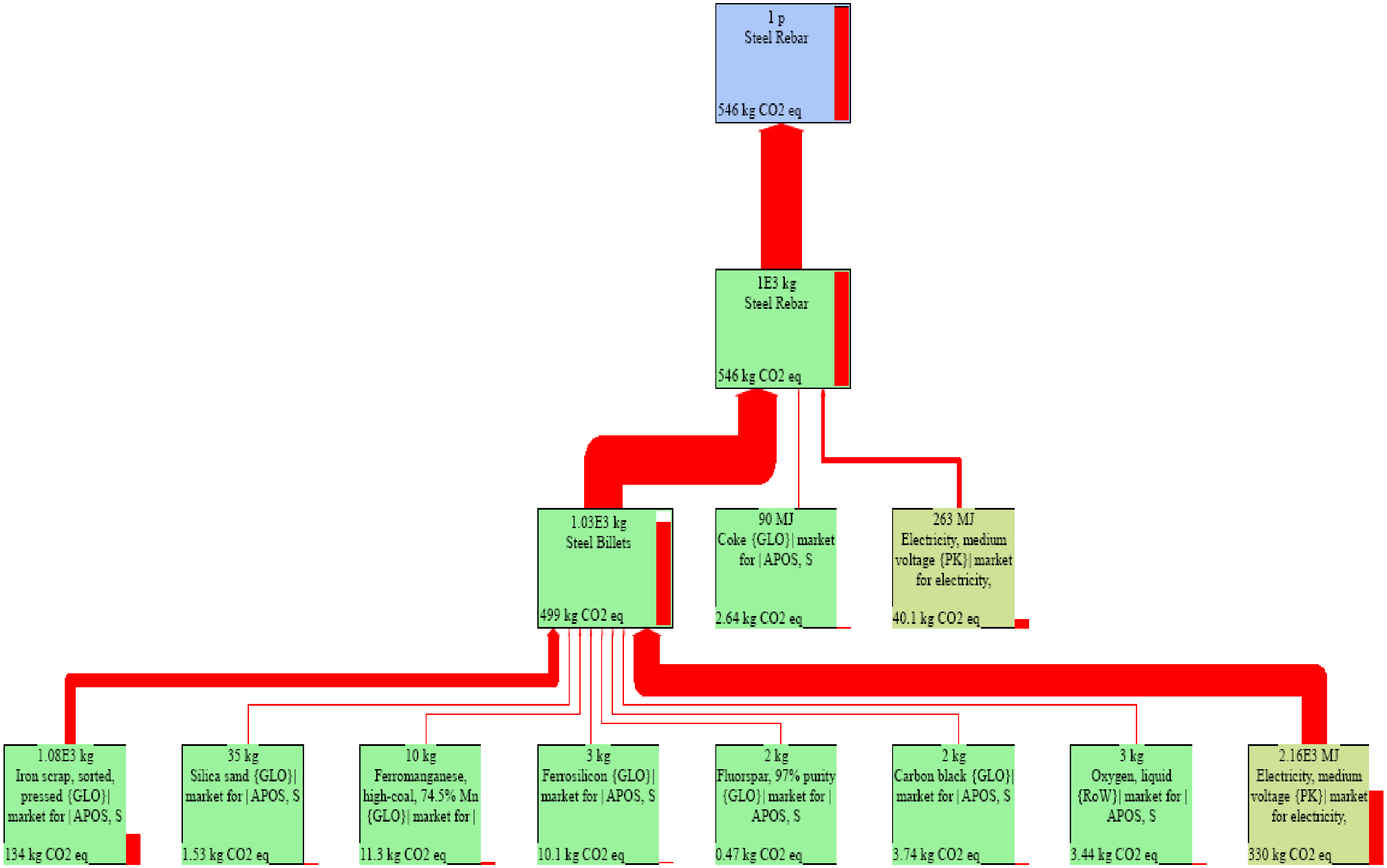


Figure 6.2. CO_2 Emission in Linear Process Scenario

Table 6.7. Characterization result of 1 t of Steel Rebar Production through linear process

Process	**Project**	**Unit**	**Total**	**Steel Rebar**
Total of all processes		**kg CO2 eq**	**545.75**	**545.75**
Carbon black {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	3.739394	3.739394
Coke {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	2.638551	2.638551
Electricity, medium voltage {PK}| market for electricity, medium voltage | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	369.8688	369.8688
Ferromanganese, high-coal, 74.5% Mn {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	11.26195	11.26195
Ferrosilicon {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	10.0633	10.0633
Fluorspar, 97% purity {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	0.470274	0.470274
Iron scrap, sorted, pressed {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	133.5231	133.5231
Oxygen, liquid {RoW}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	3.443535	3.443535
Silica sand {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	1.53303	1.53303
Steel Billets	1ton of steel rebar production	kg CO2 eq	5.5	5.5
Steel Rebar	1ton of steel rebar production	kg CO2 eq	3.708	3.708

6.2.3.2 Closed loop process

The actual and potential benefits of byproduct synergistic exchanges between and among the steel and re-rolling mills were also made (Section 4.4). The appraisals were made on the bases of life cycle assessment.

For the purpose, a life cycle inventory based upon, the closed loop process, was prepared (Table 6.8 and 6.9). The figure 6.3 succinctly elaborates the byproduct synergies considered for the assessment.

Table 6.8. Life cycle inventory of 1-tonne of steel billet production

Input and output	Units	Amount
Iron Scrap	Kg/t	1050
Ferrosilicon	Kg/t	03
Ferro-manganese	Kg/t	10
Carbon Black	Kg/t	02
Flourspar	Kg/t	02
Silica-lining	Kg/t	35
Electricity	Kwh/t	600
Surface Water	Kg/t	08
Outputs		
Emissions to Air		
CO_2	Kg/t	5.5
CO	Kg/t	0.516
NO	Kg/t	0.026
NO_2	Kg/t	0.187
Dust	Kg/t	0.043
Volatile organic compounds	Kg/t	0.001
Lead	Kg/t	0.00085
Cadmium	Kg/t	0.00003
Zinc	Kg/t	0.00651
Nickel	Kg/t	0.00001
Chromium	Kg/t	0.00003
Final Waste Flows		
Slag	Kg/t	45
Refractories	Kg/t	35
Co-Products		
Air Filter Dust	Kg/t	10

Table 6.9. Life cycle inventory of one tonne of steel rebar production

Input and output	Units	Amount
Inputs		
Steel Billets	kg/t	1,030
Electricity	kWh/t	73
Coal	Kg/t	96
Groundwater	Kg/t	32
Outputs		
Emission to Air		
CO_2	Kg/t	3.7
CO	Kg/t	0.037
SO_2	Kg/t	0.0039
NO	Kg/t	0.179
NO_2	Kg/t	0.267
Dust	Kg/t	0.0005
Final Waste Flows		
Coal Waste	Kg/t	25

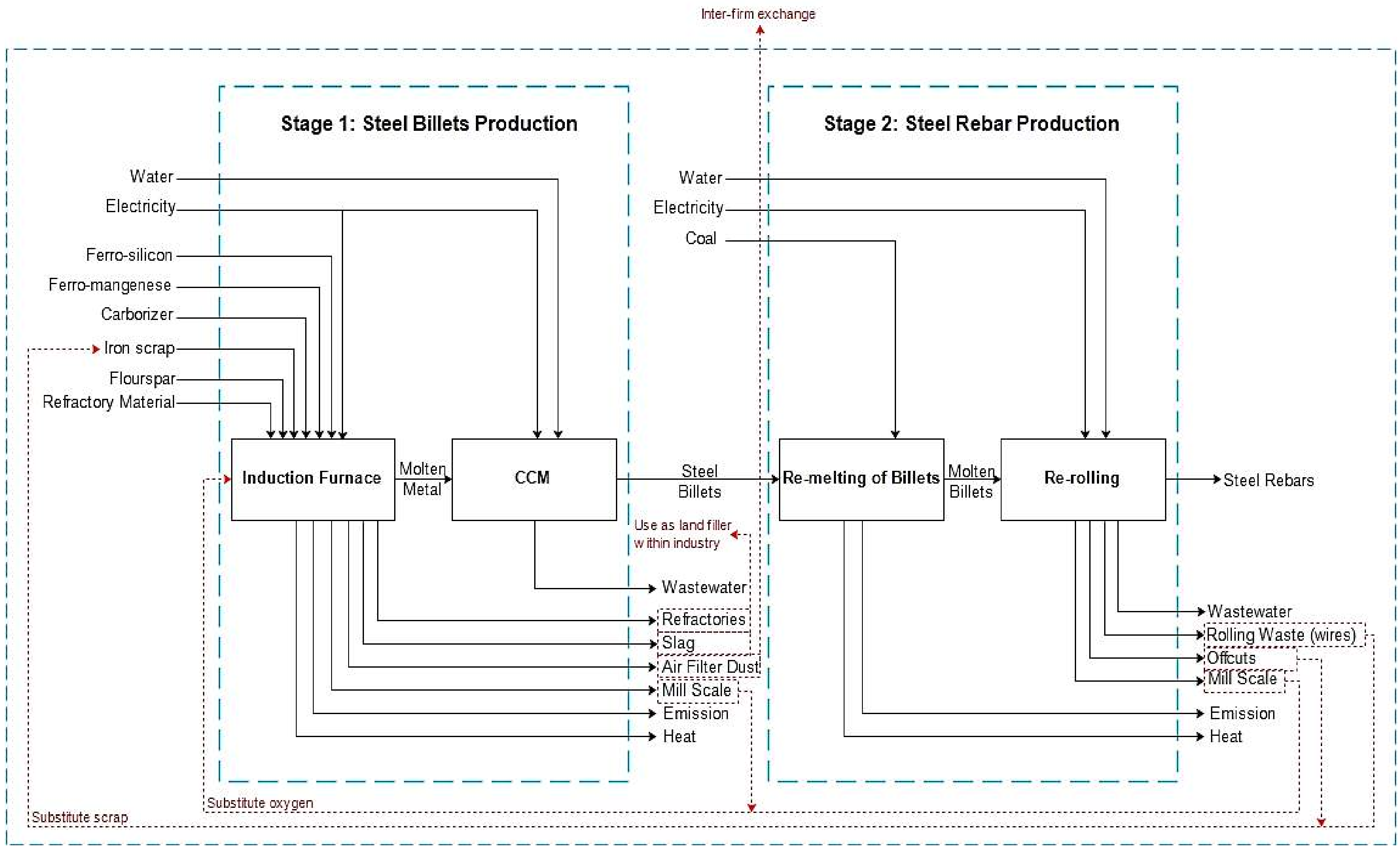


Figure 6.3. Scenario II- Closed loop Process Flow Diagram of Steel Rebar Production

The findings enable to conjecture about the amount of emissions released from such synergistic linkages. The finding revealed that approximately 535 kgCO_2 eq/t. of the emissions are released through closed loop processes during steel rebar production. The Sankey diagram of emissions (Figure 6.4) concisely illustrate the impacts of steel rebar production.

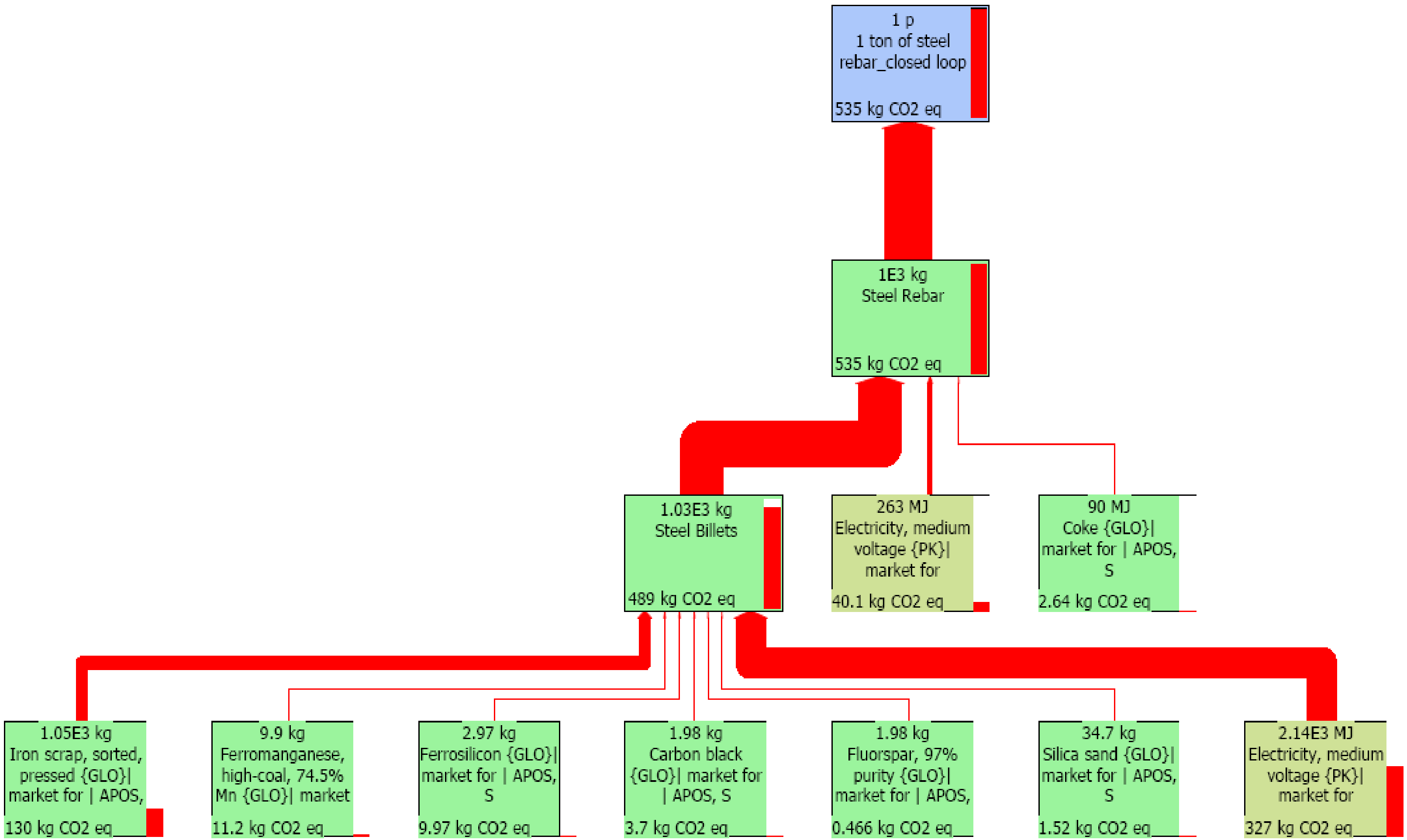


Figure 6.4. CO_2 Emission in Closed Loop Scenario

This characterization and the net amount of CO_2eq reduction from such byproducts exchanges have been condensed (Table 6.10). It was also estimated that an addition amount of 21 kgCO_2eq can be reduced by exchanging slag with cement or brick manufacturing units.

Table 6.10. Characterization result of 1t of Steel Rebar Production through closed loop process

Process	**Project**	**Unit**	**Total**	**Steel Rebar**
Total of all processes		**kg CO2 eq**	**535.0481**	**535.0481**
Carbon black {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	3.703122	3.703122
Coke {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	2.638551	2.638551
Electricity, medium voltage {PK}| market for electricity, medium voltage | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	366.6703	366.6703
Ferromanganese, high-coal, 74.5% Mn {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	11.15271	11.15271
Ferrosilicon {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	9.965682	9.965682
Fluorspar, 97% purity {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	0.465712	0.465712
Iron scrap, sorted, pressed {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	129.7793	129.7793
Silica sand {GLO}| market for | APOS, S	Ecoinvent 3 - allocation at point of substitution - system	kg CO2 eq	1.518159	1.518159
Steel Billets	1 ton steel rebar_closed loop	kg CO2 eq	5.44665	5.44665
Steel Rebar	1 ton steel rebar_closed loop	kg CO2 eq	3.708	3.708

6.4. Discussion

Iron and steel industry is the backbone for the process of industrialization. It also act as a stimulator for economic development (Khan et al., 2011; Dong et al., 2013b). During the various stages and processes in these industries, a sizeable amount of discarded material, is produced as byproducts (Burchart-Korol, 2013; Li et al., 2016; Olmez et al., 2016; Özdemir et al., 2018). These byproducts are mostly of metallic nature (Dutta et al., 2018). Therefore, the castoff industrial material is recycled and reutilized. The processed material is a valuable substitute for the virgin raw material. Besides this, utilization of discarded waste positively contribute towards solid waste reduction.

For the purpose, the required processes are carried out within the similar industrial entity or exchanged with the partner organisms. These utilizations and symbiotic partnerships not only ameliorate stresses on the natural resources but also produce monetary gains (Jacobsen, 2006; Li et al., 2016). However, the tendencies for such synergistic collaborations are less organized and, mostly, based upon informal mechanisms in the developing world (Shenoy, 2016). The lacunas find roots in the fact that the process of industrialization is in the fomenting stages in these regions. However, the thrust for industrialization is gaining recognition for ensuring socio-economic development (Khan et al., 2011; Olmez et al., 2016). Consequently, the ensuing demands for raw material and energy along with associated outputs from industrial activities are exerting their peculiar pressures on the environment. The concomitant imprints and externalities are proving stressful for the land and people of developing economies (Jacobsen, 2006; Shenoy, 2016). The compromised financial, technological and less developed natural resource bases of these transforming economies are further aggravating the situation. Therefore, careful assessments of industrial s activities is needed for the conservation of resources and sustainability of environment. These objectives are attainable through integrated management of industrial activities. These initiatives are obligatory to fulfill the international obligations. The transnational commitments are conceived to protect economic, social and ecological resources of the globe.

Therefore, the penchant for integrated industrial development in Pakistan is gaining recognition. The CPES is proving catalyst for such initiatives in this country. The desired impetus for such initiatives is being extended. This multi-purpose and multi-faceted project is stimulating industrial activities through transfer of technology and resources. Albeit, approaches and mechanisms such as LCAs are, also, gaining focus and being evaluated therefore, the present study was designed to assess the prospects of such opportunities for Pakistan. The study particularly evaluates the prospects of circular economy for the country. The findings provide the baseline information. The primary data for the study was directly retrieved from the stakeholders. The acquisition of such information is problematic in an undocumented economy such as Pakistan (Khan et al., 2011; Shenoy, 2016; Akhtar et al., 2019). However, the identification of probabilities and benchmarks are required to ensure eco-friendly industrial progression.

The findings of the study substantiate the reported assertions of Zhao et al. (2018) regarding LCA. The study formulate that the LCA is a pragmatic option for assessing the impacts of industrial activities. The study envisages that the holistic understandings rendered by the LCA are easy to comprehend and implement. These understandings are incumbent to enhance the monetary benefits. (Martin et al., 2015; Özdemir et al., 2018). The LCA provide insight to conserve the natural, human, and financial resources through integrated management of industrial activities.

Therefore, LCA based evaluations are a prerequisite for securing ISO 14040 certification. Thus, the conceptual framework of the study provide the blue print for gaining accreditation to compete in the global market. The critical findings of the study are relevant for the similar nature of industrial and manufacturing activities operating in this country.

The study also delve on the impacts of such linkages and relationships on the environment. The study particularly focuses on the waste reduction and measures to minimize CO_2 emissions. The study revealed that the intra-firm and inter-firm exchanges of by-products is a common practice in the study area. The byproducts are either utilized within the industry or exchanged with the partners except slag. The formulation and synchronization of efforts based upon the IS framework can productively contribute towards the socio-economic and ecological resilience.

The present study also render that the conceptual paradigm of the CE is relevant for the employment opportunities. These symbiotic link create new job opportunities. It is a very relevant aspect for discourses in developing countries like Pakistan. The larger proportion of younger segments in these regions is exerting pressure for employment. The exploitation of such job avenues are important for social-psychological cohesion and development. The opportunities associated with IS and CE imply for action. The ensuing financial and economic dividends will, thus, ultimately contribute towards the natural environment and social uplift of the study area.

6.5. Conclusion

This research quantifies the economic and environmental costs and benefits for the symbiosis participants. The findings highlighted the benefits incur through such symbiotic engagements. Although, these benefits are not evenly distributed among the participating organizations. Therefore, policy interventions are needed to motivate for such resource exchanges in the study area.

CONCLUSION & RECOMMENDATIONS

CHAPTER-7

CONCLUSIONS

Our natural resources and environment are being plagued by the population explosion and life style changes. The resultant disequilibrium is compelling human beings to quest for socio-ecological sustainability. Therefore, the researchers and policy makers are endeavoring to achieve these objectives.

In response to these obligations, it is incumbent to conceive pragmatic measures in the milieu of Pakistan. Hence, the present study "*Assessment of By-product Exchange Potential for Industrial Symbiosis development in Islamabad*" was conducted. The study tried to decipher the orientations and potentials of stakeholders i.e. government, industry and academia towards IS based progression in the country. Besides this, the study was designed to postulate a holistic framework for integrated management of socio-ecological resources. The findings divulged a growing focus towards such integrated efforts. However, much more needs to be done. Regrettably, in countries like Pakistan the lack of awareness and a less conducive environment for innovation are the cardinal hurdles in route to EID (Shenoy, 2016).

7.1. Key findings

7.1.1. Contemporary trends in industrial symbiosis research

IS is gaining acceptance for sustainable development. The current study evaluates the prevailing trends in IS research. The findings portrayed a diversification of interests in this discipline. The outcomes of the study affirm that industrialized nations such as China, UK and USA are spearheading this quest. Besides this, the research projects are chiefly conceived to devise strategies for reductions in carbon emission. In this regard, a growing penchant for trans-national research collaborations was also observed. However, the desired focus towards IS research was found wanting in the developing regions. Therefore, a more integrated focus towards IS research is required in these regions. Hopefully, thes scholastic efforts will contribute towards the ultimate goal of clean and green industrial production.

7.1.2. Industrial symbiosis development in Pakistan: A situational analysis

Industrial activities are gaining momentum in Pakistan. The country can serve as a hub and corridor of trade due to its geo-strategic location. The commencement of CPEC is offering fresh prospects for economic and industrial development. The expected dividends are dependent on the infrastructural advancement, competitiveness and focus on

’knowledge economy’ etc. Albeit, the industrial activities are held responsible for environmental and health problems, a synchronised paradigm of EID can reverse the scenario. Thus, the expected activities under CPEC can usher in new pathways for trade and EID in Pakistan. The study revealed Pakistan as a potentially viable region for EID. However, the lack of facilitation to encourage such developments was observed as a key weakness. Therefore, coordinated efforts are needed to overcome such gaps and lacunas. Thus, the desired initiatives are incumbent to ensure eco-friendly industrial development for socio-ecological resilience in Pakistan.

7.1.3. The potentials for by-product exchanges in industrial activities

The present study tried to assess the potentials of byproduct synergies in the study area. The findings of the study construe that a sizeable quantity of the industrial waste is recycled. Though, the stakeholders are not aware about the conceptual paradigm of industrial symbiosis, yet, they are inclined towards such collaborative ventures. The assessments helped us to identify monetary gains and eco-friendly regulations as the key enablers for synergistic collaborations. However such partnerships run into serious barriers owing to the role of the middle man and lack of awareness. Therefore, only those synergies which involve no or limited investment are successful ventures in the study area. An interactive platform can provide the requisite stimulus for EID in Pakistan. It will also significantly contribute towards cost reduction.

7.1.4. Benefits arising from byproduct exchange synergies

This research succinctly quantifies the economic and environmental benefits for the stakeholders through such symbiotic liaisons. However, the prospective benefits are neither fully utilized nor evenly distributed among the participants. These benefits can be multiplied and uniformly dispersed through planning and coordination. Policy intervention can be a viable means for motivating more regular occurrences of such exchanges in the study area.

7.2. Practical implications of the findings

The rapid population growth and resource constraints are the real challenges for EID and innovation. Therefore, policy and regulatory interventions are required to achieve the objective of sustainable development in social, economic and industrial sectors. However, a key weakness is the lack of alacrity and vision to encourage and facilitate such systematic partnerships. The following are the practical implications of the observed findings of this study.

7.2.1. Practical implication for industrial symbiosis in Pakistan

The dimensions of industrial development in Pakistan are diverse. While, on one hand the infrastructural and industrial developments through DFI under CPEC are unprecedented, the regional security dynamics and political instability are the stumbling blocks for EID. Therefore, the above-mentioned threats demand calculated responses. EID should be adopted as a holistic approach, integrating the mainstream policies for economic development rather than a stand-alone tool to overcome environmental pollution.

7.2.2. Practical implications for uncovering synergy potentials

Findings revealed that the observed symbiotic collaborations in the study area are autogenously structured relationships. These collaborations evolved without any systematic effort, tool or technique. All of these synergies are characteristically bilateral in their outlook and orientation. The majority of such collaborations are facilitated by the "middle man" whose involvement is purely haphazard. Besides this, the findings also infer that at present the focus is on the "low hanging fruit" opportunities in the IEI. While, a significant potential exists for more promising synergistic opportunities and partnerships.

7.2.3. Practical implications for partner organization in industrial sector

This research quantifies the potential economic and environmental costs and benefits which can be rather substantial once these symbiotic partnerships are regulated. Regrettably, these benefits are not evenly distributed among the participating organizations. Thus, integrated policy interventions can be a more fruitful means for motivating more regular occurrences of such resource exchanges.

7.3. Recommendations for future research

The findings based upon this study helped to formulate the following recommendations for EID in Pakistan.

1) The findings rendered a lack of clarity and compromises over policies regarding EID due to a non-conducive regulatory regime. These barriers are narrowing the horizons and strangulating all progress. Therefore, immediate attention is required to overcome the gaps/lacunas in the policy and management practices.

2) The promulgation of ambiguous environmental laws after the 18^{th} amendment are also causing confusions. The dissimilarities in the parameters among the federating units pertaining to NEQS are proving counterproductive for balanced industrial progression in the country. These anomalies are, thus, potential challenges and require rectification.

3) Promoting research and encouragements for technological innovations to utilize industrial waste and byproduct are required.
4) Future research to ensure precise quantification of waste materials and to find the means for reducing the role of the middle man are needed.
5) The initiation of an interactive platform based upon geo-spatial information about industrial activities is incumbent for the EID. It will contribute towards cost reduction and will help to yield maximum dividends for the human and natural environment.

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Zhang, Y., Zheng, H. , Fath, B. D. (2015b): Ecological network analysis of an industrial symbiosis system: a case study of the Shandong Lubei eco-industrial park. – Ecological Modelling. 306: 174-184.

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APPENDICES

APPENDIX-I

LIST OF 395 SELECTED AND REVIEWED ARTICLES

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Zhou X., Zhang H.	Research on industrial symbiosis mode logistics industrial cluster in Shenyang Economic Zone	Proceeding of 2012 International Conference on Information Management, Innovation Management and Industrial Engineering, ICIII 2012	2012	2		489	492	
Romero D., Molina A.	Green virtual enterprise breeding environments: A sustainable industrial development model for a circular economy	IFIP Advances in Information and Communication Technology	2012	380 AICT		427	436	10.1007/978-3-642-32775-9_43
Kopacek B., Schadlbauer S.	Introduction to zero WIN	Electronics Goes Green 2012+, ECG 2012 - Joint International Conference and Exhibition, Proceedings	2012					
Schadlbauer S., Kopacek B., Gallo M., Arnaiz S.	The ZeroWIN production model	Electronics Goes Green 2012+, ECG 2012 - Joint International Conference and Exhibition, Proceedings	2012					
Arranz P., Tarragó J., Vallvé X., Marwede M., Den Boer E., Rothe M., Wüst F., Middendorf A., Cocciantelli J.-M., Lippert M.	Practical demonstrator 'Design for recycling photovoltaic system'	Electronics Goes Green 2012+, ECG 2012 - Joint International Conference and Exhibition, Proceedings	2012					

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Marwede M., Schischke K., Arranz P., Hickey S., Fitzpatrick C., Ospina J., Yang M., Nissen N.F., Lang K.-D.	Methodology to identify design for recycling measures for high-tech sectors	Electronics Goes Green 2012+, ECG 2012 - Joint International Conference and Exhibition, Proceedings	2012					
Nesbit S., Stano J., Atwater J.W., Casavant T.	Cascading water: Combining GIS and system analysis to maximize water reuse	Canadian Journal of Civil Engineering	2012	39	12	1321	1327	10.1139/cjce-2012-0251
Den Boer E., Williams I., Fitzpatrick C., Arranz P., Dietrich J., Kent A., Tischer A., Durao V., Perthes H., Peagam R., Kopacek B.	Bringing all industrial networks together and next steps	Electronics Goes Green 2012+, ECG 2012 - Joint International Conference and Exhibition, Proceedings	2012					
Li G.	A paradigm of constructing industrial symbiosis and coupling in China's county-region economic sustainable development	Green Technologies and Business Practices: An IT Approach	2012			1	14	10.4018/978-1-4666-1972-2.ch001
Watts C., Binder C.R.	Simulating shocks with the hypercycles model of economic production	iEMSs 2012 - Managing Resources of a Limited Planet: Proceedings of the 6th Biennial Meeting of the International Environmental Modelling and Software Society	2012			2651	2659	
Diwekar U.	Green engineering and sustainability: A systems analysis perspective	Sustainability: Multi-Disciplinary Perspectives	2012			273	309	10.2174/978160805103811201010273

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Karkanias C., Karagiannidis A., Antonopoulos I.S., Samaras P.	Adopting rational waste management schemes: The case of Preveza municipality	Economics and Policy of Energy and the Environment	2012		3	65	79	
Hiete M., Ludwig J., Schultmann F.	Intercompany Energy Integration: Adaptation of Thermal Pinch Analysis and Allocation of Savings	Journal of Industrial Ecology	2012	16	5	689	698	10.1111/j.1530-9290.2012.00462.x
Wells P., Zapata C.	Renewable Eco-industrial Development: A New Frontier for Industrial Ecology?	Journal of Industrial Ecology	2012	16	5	665	668	10.1111/j.1530-9290.2012.00487.x
Chopra S.S., Khanna V.	Toward a network perspective for understanding resilience and sustainability in industrial symbiotic networks	IEEE International Symposium on Sustainable Systems and Technology	2012					10.1109/ISSST.2012.6227987
Lin K.-N.	Cradle to cradle at CSC: Through integrated recycling system and industrial symbiosis	AISTech - Iron and Steel Technology Conference Proceedings	2012			217	224	
Usón S., Valero A., Agudelo A.	Thermoeconomics and Industrial Symbiosis. Effect of by-product integration in cost assessment	Energy	2012	45	1	43	51	10.1016/j.energy.2012.04.016
Ohnishi S., Fujita T., Chen X., Fujii M.	Econometric analysis of the performance of recycling projects in Japanese Eco-Towns	Journal of Cleaner Production	2012	33		217	225	10.1016/j.jclepro.2012.03.027
Clark J.H., Pfaltzgraff L.	Industrial symbiosis using green chemistry	Technical Proceedings of the 2012 NSTI Nanotechnology Conference and Expo, NSTI-Nanotech 2012	2012			706	707	
Raafat T., Trokanas N., Cecelja F., Kokossis A., Yang A.	Semantically-enabled Formalisation to Support and Automate the Application of Industrial Symbiosis	Computer Aided Chemical Engineering	2012	31		1055	1059	10.1016/B978-0-444-59506-5.50042-0

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Shi L., Liu G., Guo S.	International comparison and policy recommendation on the development model of industrial symbiosis in China	Shengtai Xuebao/ Acta Ecologica Sinica	2012	32	12	3950	3957	10.5846/stxb201111131724
Shi X., Yang J., Wang R., Zhao L.	An approach for analyzing resources metabolism of industrial ecosystems	Shengtai Xuebao/ Acta Ecologica Sinica	2012	32	7	2012	2024	10.5846/stxb201104180505
Meneghetti A., Nardin G.	Enabling industrial symbiosis by a facilities management optimization approach	Journal of Cleaner Production	2012	35		263	273	10.1016/j.jclepro.2012.06.002
Raafat T., Cecelja F., Yang A., Trokanas N.	Semantic support for industrial symbiosis process	Computer Aided Chemical Engineering	2012	30		452	456	10.1016/B978-0-444-59519-5.50091-5
Trokanas N., Raafat T., Cecelja F., Kokossis A., Yang A.	Semantic Formalism for Waste and Processing Technology Classifications Using Ontology Models	Computer Aided Chemical Engineering	2012	30		167	171	10.1016/B978-0-444-59519-5.50034-4
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	Journal of Cleaner Production	2012	29-30		103	112	10.1016/j.jclepro.2012.02.009
Liu L., Zhang B., Bi J., Wei Q., He P.	The greenhouse gas mitigation of industrial parks in China: A case study of Suzhou Industrial Park	Energy Policy	2012	46		301	307	10.1016/j.enpol.2012.03.064
Geißen S.-U., Bennemann H., Horn H., Krull R., Neumann S.	Industrial wastewater treatment and recycling - Potentials and prospects [Industrieabwasserbehandlung und -recycling - Potenziale und Perspektiven]	Chemie-Ingenieur-Technik	2012	84	7	1005	1017	10.1002/cite.201200006
Andrade L.C., Míguez C.G., Gómez M.C.T., Bugallo P.M.B.	Management strategy for hazardous waste from atomised SME: Application to the printing industry	Journal of Cleaner Production	2012	35		214	229	10.1016/j.jclepro.2012.05.014

Author Name(s)	**Title**	**Source Title**	**Year**	**Vol.**	**Issue**	**P. Start**	**P. End**	**Doi**
Geng D., Li J., Liu J., Song X.	System analysis of circular economy development in coal mining area	Advanced Materials Research	2012	524-527		2735	2740	10.4028/www.scientific.net/AMR.524-527.2735
Blengini G.A., Busto M., Fantoni M., Fino D.	Eco-efficient waste glass recycling: Integrated waste management and green product development through LCA	Waste Management	2012	32	5	1000	1008	10.1016/j.wasman.2011.10.018
Golev A., Corder G.D.	Developing a classification system for regional resource synergies	Minerals Engineering	2012	29		58	64	10.1016/j.mineng.2011.10.018
Geng Y., Fu J., Sarkis J., Xue B.	Towards a national circular economy indicator system in China: An evaluation and critical analysis	Journal of Cleaner Production	2012	23	1	216	224	10.1016/j.jclepro.2011.07.005
Laybourn P., Lombardi D.R.	Industrial Symbiosis in European Policy: Overview of Recent Progress	Journal of Industrial Ecology	2012	16	1	11	12	10.1111/j.1530-9290.2011.00451.x
Lombardi D.R., Lyons D., Shi H., Agarwal A.	Industrial Symbiosis: Testing the Boundaries and Advancing Knowledge	Journal of Industrial Ecology	2012	16	1	2	7	10.1111/j.1530-9290.2012.00455.x
Paquin R.L., Howard-Grenville J.	The Evolution of Facilitated Industrial Symbiosis	Journal of Industrial Ecology	2012	16	1	83	93	10.1111/j.1530-9290.2011.00437.x
Jensen P.D., Basson L., Hellawell E.E., Leach M.	'Habitat' Suitability Index Mapping for Industrial Symbiosis Planning	Journal of Industrial Ecology	2012	16	1	38	50	10.1111/j.1530-9290.2011.00438.x
Salmi O., Hukkinen J., Heino J., Pajunen N., Wierink M.	Governing the Interplay between Industrial Ecosystems and Environmental Regulation: Heavy Industries in the Gulf of Bothnia in Finland and Sweden	Journal of Industrial Ecology	2012	16	1	119	128	10.1111/j.1530-9290.2011.00403.x
Chertow M., Ehrenfeld J.	Organizing Self-Organizing Systems: Toward a Theory of Industrial Symbiosis	Journal of Industrial Ecology	2012	16	1	13	27	10.1111/j.1530-9290.2011.00450.x

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Lombardi D.R., Laybourn P.	Redefining Industrial Symbiosis: Crossing Academic-Practitioner Boundaries	Journal of Industrial Ecology	2012	16	1	28	37	10.1111/j.1530-9290.2011.00444.x
Chen X., Fujita T., Ohnishi S., Fujii M., Geng Y.	The Impact of Scale, Recycling Boundary, and Type of Waste on Symbiosis and Recycling: An Empirical Study of Japanese Eco-Towns	Journal of Industrial Ecology	2012	16	1	129	141	10.1111/j.1530-9290.2011.00422.x
Mattila T., Lehtoranta S., Sokka L., Melanen M., Nissinen A.	Methodological Aspects of Applying Life Cycle Assessment to Industrial Symbioses	Journal of Industrial Ecology	2012	16	1	51	60	10.1111/j.1530-9290.2011.00443.x
Ashton W.S., Bain A.C.	Assessing the "Short Mental Distance" in Eco-Industrial Networks	Journal of Industrial Ecology	2012	16	1	70	82	10.1111/j.1530-9290.2011.00453.x
Boons F., Spekkink W.	Levels of Institutional Capacity and Actor Expectations about Industrial Symbiosis: Evidence from the Dutch Stimulation Program 1999-2004	Journal of Industrial Ecology	2012	16	1	61	69	10.1111/j.1530-9290.2011.00432.x
Zhou L., Hu S.-Y., Li Y., Jin Y., Zhang X.	Modeling and Optimization of a Coal-Chemical Eco-industrial System in China	Journal of Industrial Ecology	2012	16	1	105	118	10.1111/j.1530-9290.2012.00447.x
Ferrer G., Cortezia S., Neumann J.M.	Green City: Environmental and Social Responsibility in an Industrial Cluster	Journal of Industrial Ecology	2012	16	1	142	152	10.1111/j.1530-9290.2011.00442.x
Brent G.F., Allen D.J., Eichler B.R., Petrie J.G., Mann J.P., Haynes B.S.	Mineral Carbonation as the Core of an Industrial Symbiosis for Energy-Intensive Minerals Conversion	Journal of Industrial Ecology	2012	16	1	94	104	10.1111/j.1530-9290.2011.00368.x
Liu C., Ma C., Zhang K.	Going beyond the sectoral boundary: A key stage in the development of a regional industrial ecosystem	Journal of Cleaner Production	2012	22	1	42	49	10.1016/j.jclepro.2011.09.022

Author Name(s)	**Title**	**Source Title**	**Year**	**Vol.**	**Issue**	**P. Start**	**P. End**	**Doi**
Usón S., Valero A., Valero A., Costa J.	Thermoeconomic fuel impact approach for assessing resources savings in industrial symbiosis: Application to kalundborg ecoindustrial park	Proceedings of the 25th International Conference on Efficiency, Cost, Optimization and Simulation of Energy Conversion Systems and Processes, ECOS 2012	2012	3		346	356	
Valero A., Usón S., Costa J.	Exergy analysis of the industrial symbiosis model in Kalundborg	Proceedings of the 25th International Conference on Efficiency, Cost, Optimization and Simulation of Energy Conversion Systems and Processes, ECOS 2012	2012	1		406	416	
Gregson N., Crang M., Ahamed F.U., Akter N., Ferdous R., Foisal S., Hudson R.	Territorial agglomeration and industrial symbiosis: Sitakunda-Bhatiary, Bangladesh, as a secondary processing complex	Economic Geography	2012	88	1	37	58	10.1111/j.1944-8287.2011.01138.x
Li J., Wang Y., Zhou M.	Application of emergy theory in industrial ecosystem analysis	Advanced Materials Research	2012	361-363		1249	1254	10.4028/www.scientific.net/AMR.361-363.1249
Yang L., Tong L.	Research of typical EIPs based on the social network analysis	Shengtai Xuebao/ Acta Ecologica Sinica	2012	32	13	4236	4245	
Martin M., Svensson N., Fonseca J., Eklund M.	Quantifying the environmental performance of integrated bioethanol and biogas production	Renewable Energy	2013	61		109	116	10.1016/j.renene.2012.09.058
Li G.	A paradigm of constructing industrial symbiosis and coupling in China's county-region economic sustainable development	Sustainable Practices: Concepts, Methodologies, Tools, and Applications	2013	3		1218	1231	10.4018/978-1-4666-4852-4.ch068

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
MacLachlan I.	Kwinana Industrial Area: Agglomeration economies and industrial symbiosis on Western Australia's Cockburn Sound	Australian Geographer	2013	44	4	383	400	10.1080/00049182.2013.852505
Raafat T., Trokanas N., Cecelja F., Bimi X.	An ontological approach towards enabling processing technologies participation in industrial symbiosis	Computers and Chemical Engineering	2013	59		33	46	10.1016/j.compchemeng.2013.03.022
Li J., Gao Y.	Research on eco-industry symbiosis system based on complex network	Proceedings of 2012 3rd International Asia Conference on Industrial Engineering and Management Innovation, IEMI 2012	2013			759	769	10.1007/978-3-642-33012-4-76
Marinos-Kouris D., Mourtsiadis A.	Environmental limits of industrial symbiosis: The case of aluminium eco-industrial network	Fresenius Environmental Bulletin	2013	22	12	3549	3557	
Valero A., Usón S., Torres C., Valero A., Agudelo A., Costa J.	Thermoeconomic tools for the analysis of eco-industrial parks	Energy	2013	62		62	72	10.1016/j.energy.2013.07.014
[No author name available]	IFIP WG 5.7 International Conference on Advances in Production Management Systems, APMS 2012	IFIP Advances in Information and Communication Technology	2013	397	PART 1			
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	Journal of Cleaner Production	2013	59		226	238	10.1016/j.jclepro.2013.06.048
Paquin R.L., Howard-Grenville J.	Blind Dates and Arranged Marriages: Longitudinal Processes of Network Orchestration	Organization Studies	2013	34	11	1623	1653	10.1177/0170840612470230

Author Name(s)	**Title**	**Source Title**	**Year**	**Vol.**	**Issue**	**P. Start**	**P. End**	**Doi**
Liu G.-F., Chen F.-D.	NISP-based research on the system structure of urban symbiosis network in China	Applied Mechanics and Materials	2013	427-429		2923	2927	10.4028/www.scientific.net/AMM.427-429.2923
Gao X.L., Li R.Q., Li R.	Study on byproducts recycling in eco-industrial parks	Advanced Materials Research	2013	788		288	292	10.4028/www.scientific.net/AMR.788.288
Liao M.-I., Ma H.-W.	The potential environmental gains from industrial symbiosis: Evaluation of CO2 reduction through a crucial by-product	International Journal of Applied Environmental Sciences	2013	8	2	129	136	
Shi X.Q., Li X.N., Yang J.X.	Eco-management benefit analysis of industrial resources from life cycle perspective: A case study of a virtual symbiosis network	Shengtai Xuebao/ Acta Ecologica Sinica	2013	33	19	6398	6410	10.5846/stxb201304180738
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	10.1016/j.enpol.2013.06.084
Marinos-Kouris D., Mourtsiadis A.	Industrial symbiosis in Greece: A study of spatial allocation patterns	Fresenius Environmental Bulletin	2013	22	7 B	2174	2181	
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	10.1016/j.enpol.2013.05.066
Gu C., Leveneur S., Estel L., Yassine A.	Industrial symbiosis optimization control model for the exchanges of the material/energy flows in an industrial production park	IFAC Proceedings Volumes (IFAC-PapersOnline)	2013			1015	1020	10.3182/20130619-3-RU-3018.00182

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Liu G.-S., Xu S.-Q., Sun Y.-W., Han J.-Y.	Eco-industrial symbiosis network equilibrium model	Beijing Keji Daxue Xuebao/Journal of University of Science and Technology Beijing	2013	35	9	1221	1229	
Eckelman M.J., Chertow M.R.	Life cycle energy and environmental benefits of a US industrial symbiosis	International Journal of Life Cycle Assessment	2013	18	8	1524	1532	10.1007/s11367-013-0601-5
Ng R.T.L., Ng D.K.S., Tan R.R.	Systematic approach for synthesis of integrated palm oil processing complex. Part 2: Multiple owners	Industrial and Engineering Chemistry Research	2013	52	30	10221	10235	10.1021/ie400846g
Ng R.T.L., Ng D.K.S.	Systematic approach for synthesis of integrated palm oil processing complex. Part 1: Single owner	Industrial and Engineering Chemistry Research	2013	52	30	10206	10220	10.1021/ie302926q
Xiong W., Wang J., Tang W., Kong W., Zeng Z., Ouyang J., Liu M., Wang G., Huang M., Xiong D.	Establishment of integrative circular agro-ecology system for multiple agricultural industries in Three Gorges Reservoir Area	Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering	2013	29	14	203	209	10.3969/j.issn.1002-6819.2013.14.026
Trokanas N., Raafat T., Cecelja F., Kokossis A.	OFIS - Ontological Framework for Industrial Symbiosis	Computer Aided Chemical Engineering	2013	32		523	528	10.1016/B978-0-444-63234-0.50088-9
Zhu J., Ruth M.	Exploring the resilience of industrial ecosystems	Journal of Environmental Management	2013	122		65	75	10.1016/j.jenvman.2013.02.052
Zhang Y., Zheng H., Chen B., Yang N.	Social network analysis and network connectedness analysis for industrial symbiotic systems: Model development and case study	Frontiers of Earth Science	2013	7	2	169	181	10.1007/s11707-012-0349-4

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Zhang H., Dong L., Li H.-Q., Chen B., Tang Q., Fujita T.	Investigation of the residual heat recovery and carbon emission mitigation potential in a Chinese steelmaking plant: A hybrid material/energy flow analysis case study	Sustainable Energy Technologies and Assessments	2013	2	1	67	80	10.1016/j.seta.2013.03.003
Husgafvel R., Watkins G., Linkosalmi L., Dahl O.	Review of sustainability management initiatives within Finnish forest products industry companies - Translating Eu level steering into proactive initiatives	Resources, Conservation and Recycling	2013	76		1	11	10.1016/j.resconrec.2013.04.006
Pajunen N., Watkins G., Husgafvel R., Heiskanen K., Dahl O.	The challenge to overcome institutional barriers in the development of industrial residue based novel symbiosis products - Experiences from Finnish process industry	Minerals Engineering	2013	46-47		144	156	10.1016/j.mineng.2013.03.008
Hara K., Uwasu M., Yabar H., Zhang H.	Urban development and its impacts on energy and resource consumptions in the Yangtze river delta: Trends and future prospects	Yangtze River: Geography, Pollution and Environmental Implications	2013			121	127	
Boons F.	Ecological Modernization and Industrial Ecology	The Handbook of Global Companies	2013			388	402	10.1002/9781118326152.ch23
Feng L., Di J.H.	A new model of industrial symbiosis optimization	Hydraulic Engineering - Proceedings of the 2012 SREE Conference on Hydraulic Engineering, CHE 2012 and 2nd SREE Workshop on Environment and Safety Engineering, WESE 2012	2013			365	370	

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Spekkink W.	Institutional capacity building for industrial symbiosis in the Canal Zone of Zeeland in the Netherlands: A process analysis	Journal of Cleaner Production	2013	52		342	355	10.1016/j.jclepro.2013.02.025
Boons F.	Industrial Symbiosis and the Chemical Industry: Between Exploration and Exploitation	Management Principles of Sustainable Industrial Chemistry: Theories, Concepts and Industrial Examples for Achieving Sustainable Chemical Products and Processes from a Non-Technological Viewpoint	2013			131	145	10.1002/9783527649488.ch9
Montastruc L., Boix M., Pibouleau L., Azzaro-Pantel C., Domenech S.	On the flexibility of an eco-industrial park (EIP) for managing industrial water	Journal of Cleaner Production	2013	43		1	11	10.1016/j.jclepro.2012.12.039
Watkins G., Husgafvel R., Pajunen N., Dahl O., Heiskanen K.	Overcoming institutional barriers in the development of novel process industry residue based symbiosis products - Case study at the EU level	Minerals Engineering	2013	41		31	40	10.1016/j.mineng.2012.10.003
Termsinvanich P., Thadaniti S., Wiwattanadate D.	Conceptual model for effective implementation of industrial symbiosis: A case study of Mab-Ta-Phut industrial estate	Mediterranean Journal of Social Sciences	2013	4	1	133	139	10.5901/mjss.2013.v4n1p133
Albino V., Garavelli A.C., Romano V.A.	A Classification of industrial symbiosis networks: A focus on materials and energy recovery	IFIP Advances in Information and Communication Technology	2013	397	PAR T 1	216	223	10.1007/978-3-642-40352-1_28
Wang G., Feng X., Chu K.H.	A novel approach for stability analysis of industrial symbiosis systems	Journal of Cleaner Production	2013	39		9	16	10.1016/j.jclepro.2012.08.031

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Antonopoulos I.S., Zouboulis A.I., Karagiannidis A., Samaras P.	Applying dpsir analysis as a decision support tool for fostering industrial symbiosis concept	Fresenius Environmental Bulletin	2013	22	12 C	3830	3839	
Ng W.P.Q., Lam H.L.	Sustainable supply network design through optimisation with clustering technique integration	Chemical Engineering Transactions	2013	35		661	666	10.3303/CET1335110
Rankin W.J.	Towards zero waste production in the minerals and metals sector	TMS Annual Meeting	2013			392	403	
Gu C., Leveneur S., Estel L., Yassine A.	Modeling and optimization of material/energy flow exchanges in an eco-industrial park	Energy Procedia	2013	36		243	252	10.1016/j.egypro.2013.07.028
Mohammed F.A., Yao H.M., OludayoTadé M., Biswas W.	A framework for synergy evaluation and development in heavy industries	Re-Engineering Manufacturing for Sustainability - Proceedings of the 20th CIRP International Conference on Life Cycle Engineering	2013			591	595	
Gu C., Estel L., Yassine A., Leveneur S.	A multiobjective optimization model for designing and optimizing an ecological industrial park	Proceedings - International Conference on Natural Computation	2013			595	600	10.1109/ICNC.2013.6818046
Wood B.M., Jader L.R., Schendel F.J., Hahn N.J., Valentas K.J., Mcnamara P.J., Novak P.M., Heilmann S.M.	Industrial symbiosis: Corn ethanol fermentation, hydrothermal carbonization, and anaerobic digestion	Biotechnology and Bioengineering	2013	110	10	2624	2632	10.1002/bit.24924

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Kreiger M.A., Shonnard D.R., Pearce J.M.	Life cycle analysis of silane recycling in amorphous silicon-based solar photovoltaic manufacturing	Resources, Conservation and Recycling	2013	70		44	49	10.1016/j.resconrec.2012.10.002
Jung S., Dodbiba G., Chae S.H., Fujita T.	A novel approach for evaluating the performance of eco-industrial park pilot projects	Journal of Cleaner Production	2013	39		50	59	10.1016/j.jclepro.2012.08.030
Mohammed F.A., Biswas W.K., Yao H.M., Tadé M.O.	Assessment of industrial by-product synergies from process engineering and sustainability principles	Progress in Industrial Ecology	2013	8	3	156	165	10.1504/PIE.2013.060663
Romero E., Ruiz M.C.	Framework for applying a complex adaptive system approach to model the operation of eco-industrial parks	Journal of Industrial Ecology	2013	17	5	731	741	10.1111/jiec.12032
Patala S., Hämäläinen S., Jalkala A., Pesonen H.-L.	Towards a broader perspective on the forms of eco-industrial networks	Journal of Cleaner Production	2014	82		166	178	10.1016/j.jclepro.2014.06.059
Giurco D., Prior J., Boydell S.	Industrial ecology and carbon property rights	Journal of Cleaner Production	2014	80		211	223	10.1016/j.jclepro.2014.05.079
Short S.W., Bocken N.M., Barlow C.Y., Chertow M.R.	From refining sugar to growing tomatoes: Industrial ecology and business model evolution short et al. from refining sugar to growing tomatoes	Journal of Industrial Ecology	2014					10.1111/jiec.12171
Yu B., Li X., Shi L., Qian Y.	Quantifying CO2 emission reduction from industrial symbiosis in integrated steel mills in China	Journal of Cleaner Production	2014					10.1016/j.jclepro.2014.08.015
Chopra S.S., Khanna V.	Understanding resilience in industrial symbiosis networks: Insights from network analysis	Journal of Environmental Management	2014	141		86	94	10.1016/j.jenvman.2013.12.038

Author Name(s)	**Title**	**Source Title**	**Year**	**Vol.**	**Issue**	**P. Start**	**P. End**	**Doi**
Schiller F., Penn A.S., Basson L.	Analyzing networks in industrial ecology - A review of Social-Material Network Analyses	Journal of Cleaner Production	2014	76		1	11	10.1016/j.jclepro.2014.03.029
Li W., Cui Z., Han F.	Methods for assessing the energy-saving efficiency of industrial symbiosis in industrial parks	Environmental Science and Pollution Research	2014					10.1007/s11356-014-3327-4
Li W., Cui Z., Han F.	Methods for assessing the energy-saving efficiency of industrial symbiosis in industrial parks	Environmental Science and Pollution Research	2014	22	1	275	285	10.1007/s11356-014-3327-4
Trokanas N., Cecelja F., Raafat T.	Semantic input/output matching for waste processing in industrial symbiosis	Computers and Chemical Engineering	2014	66		259	268	10.1016/j.compchemeng.2014.02.010
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	Journal of Cleaner Production	2014	74		1	16	10.1016/j.jclepro.2014.03.050
Harmsen J.	Novel sustainable industrial processes: From idea to commercial scale implementation	Green Processing and Synthesis	2014	3	3	189	193	10.1515/gps-2013-0102
Jiao W., Boons F.	Toward a research agenda for policy intervention and facilitation to enhance industrial symbiosis based on a comprehensive literature review	Journal of Cleaner Production	2014	67		14	25	10.1016/j.jclepro.2013.12.050
Simboli A., Taddeo R., Morgante A.	Analysing the development of Industrial Symbiosis in a motorcycle local industrial network: The role of contextual factors	Journal of Cleaner Production	2014	66		372	383	10.1016/j.jclepro.2013.11.045
Aviso K.B.	Design of robust water exchange networks for eco-industrial symbiosis	Process Safety and Environmental Protection	2014	92	2	160	170	10.1016/j.psep.2012.12.001

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Zhu J., Ruth M.	The development of regional collaboration for resource efficiency: A network perspective on industrial symbiosis	Computers, Environment and Urban Systems	2014	44		37	46	10.1016/j.compenvurbsys.2013.11.001
Zhang B., Wang Z.	Inter-firm collaborations on carbon emission reduction within industrial chains in China: Practices, drivers and effects on firms' performances	Energy Economics	2014	42		115	131	10.1016/j.eneco.2013.12.006
Mirabella N., Castellani V., Sala S.	Current options for the valorization of food manufacturing waste: A review	Journal of Cleaner Production	2014	65		28	41	10.1016/j.jclepro.2013.10.051
Gonela V., Zhang J.	Design of the optimal industrial symbiosis system to improve bioethanol production	Journal of Cleaner Production	2014	64		513	534	10.1016/j.jclepro.2013.07.059
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	10.1016/j.enpol.2013.10.019
Park H.-S., Behera S.K.	Methodological aspects of applying eco-efficiency indicators to industrial symbiosis networks	Journal of Cleaner Production	2014	64		478	485	10.1016/j.jclepro.2013.08.032
Yu C., De Jong M., Dijkema G.P.J.	Process analysis of eco-industrial park development - The case of Tianjin, China	Journal of Cleaner Production	2014	64		464	477	10.1016/j.jclepro.2013.09.002
Tian J., Liu W., Lai B., Li X., Chen L.	Study of the performance of eco-industrial park development in China	Journal of Cleaner Production	2014	64		486	494	10.1016/j.jclepro.2013.08.005
Liu G.F., Ma Y.T.	Study on by-product synergy and eco-industrial parks in China based on american experience	Applied Mechanics and Materials	2014	472		884	888	10.4028/www.scientific.net/AMM.472.884

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Romero E., Ruiz M.C.	Proposal of an agent-based analytical model to convert industrial areas in industrial eco-systems	Science of the Total Environment	2014	468-469		394	405	10.1016/j.scitotenv.2013.08.049
Notarnicola B., Tassielli G., Renzulli P.A.	Potential developments of industrial symbiosis in the Taranto productive district	Pathways to Environmental Sustainability: Methodologies and Experiences	2014			215	224	10.1007/978-3-319-03826-1_21
Teh B.T., Ho C.S., Matsuoka Y., Chau L.W., Gomi K.	Determinant factors of industrial symbiosis: Greening Pasir Gudang industrial park	IOP Conference Series: Earth and Environmental Science	2014	18	1			10.1088/1755-1315/18/1/012162
Park J.Y., Park H.-S.	Securing a competitive advantage through industrial symbiosis development: The case of steam networking practices in Ulsan park and park competitive advantage and industrial symbiosis	Journal of Industrial Ecology	2014	18	5	677	683	10.1111/jiec.12158
Deutz P.	Food for thought: Seeking the essence of industrial symbiosis	Pathways to Environmental Sustainability: Methodologies and Experiences	2014			3	11	10.1007/978-3-319-03826-1_1
Trokanas N., Cecelja F., Yu M., Raafat T.	Optimising environmental performance of symbiotic networks using semantics	Computer Aided Chemical Engineering	2014	33		847	852	10.1016/B978-0-444-63456-6.50142-3
Zhang Y., Zheng H., Chen B., Su M., Liu G.	A review of industrial symbiosis research: theory and methodology	Frontiers of Earth Science	2014	9	1	91	104	10.1007/s11707-014-0445-8
Geng Y., Liu Z., Xue B., Dong H., Fujita T., Chiu A.	Emergy-based assessment on industrial symbiosis: a case of Shenyang Economic and Technological Development Zone	Environmental Science and Pollution Research	2014	21	23	13572	13587	10.1007/s11356-014-3287-8

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Paquin R.L., Tilleman S.G., Howard-Grenville J.	Is there cash in that trash?: Factors influencing industrial symbiosis exchange initiation and completion	Journal of Industrial Ecology	2014	18	2	268	279	10.1111/jiec.12120
Xu S., Liu G., Lv W., Liu Y.	The nonlinear complementarity model of industrial symbiosis network equilibrium problem	RAIRO - Operations Research	2014	48	4	559	594	10.1051/ro/2014024
Boons F., Spekkink W., Jiao W.	A Process Perspective on Industrial Symbiosis: Theory, Methodology, and Application Boons et al. A Process Perspective on Industrial Symbiosis	Journal of Industrial Ecology	2014	18	3	341	355	10.1111/jiec.12116
Trokanas N., Cecelja F., Raafat T.	Towards a re-usable ontology for waste processing	Computer Aided Chemical Engineering	2014	33		841	846	10.1016/B978-0-444-63456-6.50141-1
Cutaia L., Morabito R., Barberio G., Mancuso E., Brunori C., Spezzano P., Mione A., Mungiguerra C., Li Rosi O., Cappello F.	The project for the implementation of the industrial symbiosis platform in sicily: The progress after the first year of operation	Pathways to Environmental Sustainability: Methodologies and Experiences	2014			205	214	10.1007/978-3-319-03826-1_20
Golev A., Corder G.D., Giurco D.P.	Industrial symbiosis in gladstone: A decade of progress and future development	Journal of Cleaner Production	2014	84	1	421	429	10.1016/j.jclepro.2013.06.054
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	Journal of Environmental Chemical Engineering	2014	2	1	652	664	10.1016/j.jece.2013.11.003

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Schiller F., Penn A., Druckman A., Basson L., Royston K.	Exploring Space, Exploiting Opportunities: The Case for Analyzing Space in Industrial Ecology Schiller et al. Exploring Space, Exploiting Opportunities	Journal of Industrial Ecology	2014	18	6	792	798	10.1111/jiec.12140
Yu C., Davis C., Dijkema G.P.J.	Understanding the evolution of industrial symbiosis research: A bibliometric and network analysis (1997-2012)	Journal of Industrial Ecology	2014	18	2	280	293	10.1111/jiec.12073
Alfaro J., Miller S.	Applying Industrial Symbiosis to Smallholder Farms: Modeling a Case Study in Liberia, West Africa	Journal of Industrial Ecology	2014	18	1	145	154	10.1111/jiec.12077
Zou Y.-L., Li C.-F., Yao Z.-D., Cao Y.-Y.	AN research on energy management and cooperation performance in eco-industrial symbiosis network	Advanced Materials Research	2014	986-987		211	214	10.4028/www.scientific.net/AMR.986-987.211
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	Computer Aided Chemical Engineering	2014	34		579	584	10.1016/B978-0-444-63433-7.50081-X
Li C., Feng L.	Evolutionary game analysis of the eco-industrial symbiosis network considering externality	Complex Systems and Complexity Science	2014	11	3	58	64	10.13306/j.1672-3813.2014.03.009
Ng R.T.L., Wan Y.K., Ng D.K.S., Tan R.R.	Stability analysis of symbiotic bioenergy parks	Chemical Engineering Transactions	2014	39		859	864	10.3303/CET1439144
Noureldin M.B., Farooq Z., Al-Owaidh M., Al-Saed H.	New systematic approach using combined constraints logic propagation and mathematical programming techniques for energy efficient synthesis of eco-industrial parks	Process Development Division 2014 - Core Programming Area at the 2014 AIChE Annual Meeting	2014			305	307	
Benjamin M.F.D., Tan R.R., Razon L.F.	A methodology for criticality analysis in symbiotic bioenergy parks	Energy Procedia	2014	61		41	44	10.1016/j.egypro.2014.11.901

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Ramli A., Mokhtar M., Aziz B.A., Ngah N.A.	The cooperative approach in managing safety issues for Halal industrial parks in Malaysia: Embracing opportunity	Progress in Industrial Ecology	2014	8	4	295	318	10.1504/PIE.2014.066805
Carmen Lenuta T.	Contributions to the fondation of a waste management plan on an area level	International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM	2014	3	5	95	101	
Short S.W., Bocken N.M.P., Barlow C.Y., Chertow M.R.	From refining sugar to growing tomatoes: Industrial ecology and business model evolution	Journal of Industrial Ecology	2014	18	5	603	618	10.1111/jiec.12171
Arranz P., Anzizu M., Pineau A., Marwede M., Den Boer E., Den Boer J., Cocciantelli J.-M., Williams I.D., Obersteiner G., Scherhaufer S., Vallvé X.	The development of a resourceefficient photovoltaic system	Proceedings of Institution of Civil Engineers: Waste and Resource Management	2014	167	3	109	122	10.1680/warm.13.00027
Steingrimsson J.G., Seliger G.	Conceptual framework for near-to-site waste cycle design	Procedia CIRP	2014	15		272	277	10.1016/j.procir.2014.06.014
Obersteiner G., Pertl A.	Waste Avoidance Through Industrial Symbiosis [Abfallvermeidung durch industrielle Symbiose]	Osterreichische Wasser- und Abfallwirtschaft	2014	66		417	423	10.1007/s00506-014-0191-x
Dong H., Ohnishi S., Fujita T., Geng Y., Fujii M., Dong L.	Achieving carbon emission reduction through industrial & urban symbiosis: A case of Kawasaki	Energy	2014	64		277	286	10.1016/j.energy.2013.11.005

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Noureldin M.B., Farooq Z., Al-Owaidh M., Al-Saed H.	New systematic approach using combined constraints logic propagation and mathematical programming techniques for energy efficient synthesis of eco-industrial parks	Sustainable Engineering Forum 2014 - Core Programming Area at the 2014 AIChE Annual Meeting	2014			351	353	
Li X., Xiao R., Zeng Y., Yao Z.	Vulnerability analysis of symbiotic network in eco-industrial parks	Shengtai Xuebao/ Acta Ecologica Sinica	2014	34	16	4746	4755	10.5846/stxb201212191820
Eckelman M.J., Ashton W., Arakaki Y., Hanaki K., Nagashima S., Malone-Lee L.C.	Island waste management systems: Statistics, challenges, and opportunities for applied industrial ecology	Journal of Industrial Ecology	2014	18	2	306	317	10.1111/jiec.12113
Stubbs W.	Exploration of barriers to mainstreaming industrial ecosystems in Australia	Progress in Industrial Ecology	2014	8	4	319	335	10.1504/PIE.2014.066814
Rosano M., Schianetz K.	Measuring sustainability performance in industrial parks: A case study of the Kwinana industrial area	International Journal of Sustainable Development	2014	17	3	261	280	10.1504/IJSD.2014.064181
Wang G., Feng X., Khim Hoong C.	Symbiosis analysis on industrial ecological system	Chinese Journal of Chemical Engineering	2014	22	6	690	698	10.1016/S1004-9541(14)60084-7
Dean C.A., Fath B.D., Chen B.	Indicators for an expanded business operations model to evaluate eco-smart corporate communities	Ecological Indicators	2014	47		137	148	10.1016/j.ecolind.2014.07.010
Campos T.R.T., Fonseca M.V.A., Morais R.M.N.	Reverse logistics: A route that only makes sense when adopting a systemic vision	WIT Transactions on Ecology and the Environment	2014	180		41	52	10.2495/WM140041
Kikuchi Y., Kimura S., Okamoto Y., Koyama M.	A scenario analysis of future energy systems based on an energy flow model represented as functionals of technology options	Applied Energy	2014	132		586	601	10.1016/j.apenergy.2014.07.005

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Spekkink W.	Building capacity for sustainable regional industrial systems: An event sequence analysis of developments in the Sloe Area and Canal Zone	Journal of Cleaner Production	2014					10.1016/j.jclepro.2014.08.028
Cecelja F., Trokanas N., Raafat T., Yu M.	Semantic algorithm for Industrial Symbiosis network synthesis	Computers and Chemical Engineering	2015	83		248	266	10.1016/j.compchemeng.2015.04.031
Chen P.-C., Ma H.-W.	Using an Industrial Waste Account to Facilitate National Level Industrial Symbioses by Uncovering the Waste Exchange Potential	Journal of Industrial Ecology	2015	19	6	950	962	10.1111/jiec.12236
Meylan F.D., Moreau V., Erkman S.	CO2 utilization in the perspective of industrial ecology, an overview	Journal of CO2 Utilization	2015	12		101	108	10.1016/j.jcou.2015.05.003
Patrício J., Costa I., Niza S.	Urban material cycle closing - Assessment of industrial waste management in Lisbon region	Journal of Cleaner Production	2015	106		389	399	10.1016/j.jclepro.2014.08.069
Kwon G.-R., Woo S.H., Lim S.-R.	Industrial ecology-based strategies to reduce the embodied CO2 of magnesium metal	Resources, Conservation and Recycling	2015	104		206	212	10.1016/j.resconrec.2015.08.008
Spekkink W.	Varieties of industrial symbiosis	International Perspectives on Industrial Ecology	2015			142	156	10.4337/9781781003572.00017
Patchell J.	Intersection of industrial symbiosis and product-based industrial ecologies: Considerations from the Japanese home appliance industry	International Perspectives on Industrial Ecology	2015			175	190	10.4337/9781781003572.00019
Wang Q., Deutz P., Gibbs D.	UK-China collaboration for industrial symbiosis: A multi-level approach to policy transfer analysis	International Perspectives on Industrial Ecology	2015			89	107	10.4337/9781781003572.00014

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Olayide O.E.	Industrial ecology, industrial symbiosis and eco-industrial parks in Africa: Issues for sustainable development	International Perspectives on Industrial Ecology	2015			30	45	10.4337/9781781003572.00011
Boons F., Spekkink W., Isenmann R., Baas L., Eklund M., Brullot S., Deutz P., Gibbs D., Massard G., Arozamena E.R., Puente C.R., Verguts V., Davis C., Korevaar G., Costa I., Baumann H.	Comparing industrial symbiosis in Europe: Towards a conceptual framework and research methodology	International Perspectives on Industrial Ecology	2015			69	88	10.4337/9781781003572.00013
Deutz P., Lyons D.I., Bi J.	International perspectives on industrial ecology	International Perspectives on Industrial Ecology	2015			1	249	10.4337/9781781003572
Iacondini A., Mencherini U., Passarini F., Vassura I., Fanelli A., Cibotti P.	Feasibility of Industrial Symbiosis in Italy as an Opportunity for Economic Development: Critical Success Factor Analysis, Impact and Constrains of the Specific Italian Regulations	Waste and Biomass Valorization	2015	6	5	865	874	10.1007/s12649-015-9380-5
Madsen J.K., Boisen N., Nielsen L.U., Tackmann L.H.	Industrial Symbiosis Exchanges: Developing a Guideline to Companies	Waste and Biomass Valorization	2015	6	5	855	864	10.1007/s12649-015-9417-9
Zoccola M., Montarsolo A., Mossotti R., Patrucco A., Tonin C.	Green Hydrolysis as an Emerging Technology to Turn Wool Waste into Organic Nitrogen Fertilizer	Waste and Biomass Valorization	2015	6	5	891	897	10.1007/s12649-015-9393-0

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Lombardi L., Carnevale E., Baciocchi R., Costa G.	Biogas Upgrading by a Combination of Innovative Treatments Based on Carbonation of Waste Incineration Residues	Waste and Biomass Valorization	2015	6	5	791	803	10.1007/s12649-015-9413-0
Earley K.	Industrial symbiosis: Harnessing waste energy and materials for mutual benefit	Renewable Energy Focus	2015	16	4	75	77	10.1016/j.ref.2015.09.011
Atkins M.J., Walmsley M.R.W., Walmsley T.G., Neale J.R.	Integration of biomass conversion technologies and geothermal heat into a model wood processing cluster	Chemical Engineering Transactions	2015	45		169	174	10.3303/CET1545029
Gonela V., Zhang J., Osmani A.	Stochastic optimization of sustainable industrial symbiosis based hybrid generation bioethanol supply chains	Computers and Industrial Engineering	2015	87		40	65	10.1016/j.cie.2015.04.025
Abate S., Lanzafame P., Perathoner S., Centi G.	New Sustainable Model of Biorefineries: Biofactories and Challenges of Integrating Bio- and Solar Refineries	ChemSusChem	2015	8	17	2854	2866	10.1002/cssc.201500277
Benjamin M.F.D., Ubando A.T., Razon L.F., Tan R.R.	Analyzing the disruption resilience of bioenergy parks using dynamic inoperability input–output modeling	Environment Systems and Decisions	2015	35	3	351	362	10.1007/s10669-015-9562-5
Zhang Y., Zheng H., Fath B.D.	Ecological network analysis of an industrial symbiosis system: A case study of the Shandong Lubei eco-industrial park	Ecological Modelling	2015	306		174	184	10.1016/j.ecolmodel.2014.05.005
Beloborodko A., Rosa M.	The Use of Performance Indicators for Analysis of Resource Efficiency Measures	Energy Procedia	2015	72		337	344	10.1016/j.egypro.2015.06.049
Yu C., Dijkema G.P.J., de Jong M.	What Makes Eco-Transformation of Industrial Parks Take Off in China?	Journal of Industrial Ecology	2015	19	3	441	456	10.1111/jiec.12185

Author Name(s)	**Title**	**Source Title**	**Year**	**Vol.**	**Issue**	**P. Start**	**P. End**	**Doi**
Lopes M.S.G.	Engineering biological systems toward a sustainable bioeconomy	Journal of Industrial Microbiology and Biotechnology	2015	42	6	813	838	10.1007/s10295-015-1606-9
Rončević B., Fric U.	Researching industrial symbiosis: Challenges and dilemmas	Applied Modelling and Computing in Social Sciences	2015			35	49	10.3726/978-3-653-05821-5
Päivärinne S., Hjelm O., Gustafsson S.	Excess heat supply collaborations within the district heating sector: Drivers and barriers	Journal of Renewable and Sustainable Energy	2015	7	3			10.1063/1.4921759
Li Y., Shi L.	The Resilience of Interdependent Industrial Symbiosis Networks: A Case of Yixing Economic and Technological Development Zone	Journal of Industrial Ecology	2015	19	2	264	273	10.1111/jiec.12267
Chandra-Putra H., Chen J., Andrews C.J.	Eco-Evolutionary Pathways Toward Industrial Cities	Journal of Industrial Ecology	2015	19	2	274	284	10.1111/jiec.12234
Strazza C., Magrassi F., Gallo M., Del Borghi A.	Life Cycle Assessment from food to food: A case study of circular economy from cruise ships to aquaculture	Sustainable Production and Consumption	2015	2		40	51	10.1016/j.spc.2015.06.004
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	Ecological Economics	2015	111		65	75	10.1016/j.ecolecon.2015.01.005
Bakshi B.R., Ziv G., Lepech M.D.	Techno-ecological synergy: A framework for sustainable engineering	Environmental Science and Technology	2015	49	3	1752	1760	10.1021/es5041442
Lam H.L., How B.S., Hong B.H.	Green supply chain toward sustainable industry development	Assessing and Measuring Environmental Impact and Sustainability	2015			409	449	10.1016/B978-0-12-799968-5.00012-9
Yu F., Han F., Cui Z.	Evolution of industrial symbiosis in an eco-industrial park in China	Journal of Cleaner Production	2015	87	C	339	347	10.1016/j.jclepro.2014.10.058

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Chertow M., Park J.	Scholarship and practice in industrial symbiosis: 1989–2014	Taking Stock of Industrial Ecology	2015			87	116	10.1007/978-3-319-20571-7_5
Cecelja F., Raafat T., Trokanas N., Innes S., Smith M., Yang A., Zorgios Y., Korkofygas A., Kokossis A.	E-Symbiosis: Technology-enabled support for Industrial Symbiosis targeting Small and Medium Enterprises and innovation	Journal of Cleaner Production	2015	98		336	352	10.1016/j.jclepro.2014.08.051
Martin M., Svensson N., Eklund M.	Who gets the benefits? An approach for assessing the environmental performance of industrial symbiosis	Journal of Cleaner Production	2015	98		263	271	10.1016/j.jclepro.2013.06.024
Hein A.M., Jankovic M., Farel R., Sam Lei I., Yannou B.	Modeling industrial symbiosis using design structure matrices	Modeling and Managing Complex Systems - Proceedings of the 17th International DSM Conference	2015			209	219	
Paquin R.L., Busch T., Tilleman S.G.	Creating economic and environmental value through industrial symbiosis	Long Range Planning	2015	48	2	95	107	10.1016/j.lrp.2013.11.002
Martin M.	Quantifying the environmental performance of an industrial symbiosis network of biofuel producers	Journal of Cleaner Production	2015	102		202	212	10.1016/j.jclepro.2015.04.063
Gaidajis G., Kakanis I.	Examination of industrial symbiosis potential interactions in an industrial area of NE greece	Journal of Engineering Science and Technology Review	2015	8	3	130	135	
Bertels S., Bowen F.	Taking Stock, Looking Ahead: Editors' Introduction to the Inaugural Organization & Environment Review Issue	Organization and Environment	2015	28	1	3	7	10.1177/1086026615576798
Liu C., Côté R.P., Zhang K.	Implementing a three-level approach in industrial symbiosis	Journal of Cleaner Production	2015	87	1	318	327	10.1016/j.jclepro.2014.09.067

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Spekkink W.	Building capacity for sustainable regional industrial systems: An event sequence analysis of developments in the Sloe Area and Canal Zone	Journal of Cleaner Production	2015	98		133	144	10.1016/j.jclepro.2014.08.028
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	10.1016/j.procir.2015.01.066
Aid G., Brandt N., Lysenkova M., Smedberg N.	Looplocal - A heuristic visualization tool to support the strategic facilitation of industrial symbiosis	Journal of Cleaner Production	2015	98		328	335	10.1016/j.jclepro.2014.08.012
Trokanas N., Cecelja F., Raafat T.	Semantic approach for pre-assessment of environmental indicators in Industrial Symbiosis	Journal of Cleaner Production	2015	96		349	361	10.1016/j.jclepro.2013.12.046
Rosa M., Beloborodko A.	A decision support method for development of industrial synergies: Case studies of Latvian brewery and wood-processing industries	Journal of Cleaner Production	2015	105		461	470	10.1016/j.jclepro.2014.09.061
Leigh M., Li X.	Industrial ecology, industrial symbiosis and supply chain environmental sustainability: A case study of a large UK distributor	Journal of Cleaner Production	2015	106		632	643	10.1016/j.jclepro.2014.09.022
Trokanas N., Bussemaker M., Velliou E., Tokos H., Cecelja F.	BiOnto: An Ontology for Biomass and Biorefining Technologies	Computer Aided Chemical Engineering	2015	37		959	964	10.1016/B978-0-444-63577-8.50005-X

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Chudobiecki J., Wanat L.	Industrial symbiosis and green business parks in the wood-based sector in Poland	Wood Processing and Furniture Manufacturing Challenges on the World Market and Wood-Based Energy Goes Global - Proceedings of Scientific Papers	2015			221	228	
Albino V., Fraccascia L., Savino T.	Industrial Symbiosis for a Sustainable City: Technical, Economical and Organizational Issues	Procedia Engineering	2015	118		950	957	10.1016/j.proeng.2015.08.536
Bailey M., Gadd A.	Quantifying the potential of industrial symbiosis: The LOCIMAP project, with applications in the humber region	Taking Stock of Industrial Ecology	2015			343	357	10.1007/978-3-319-20571-7_19
Yu B., Li X., Shi L., Qian Y.	Quantifying CO2 emission reduction from industrial symbiosis in integrated steel mills in China	Journal of Cleaner Production	2015	103		801	810	10.1016/j.jclepro.2014.08.015
Wu J., Li C., Yang F.	The disposition of chromite ore processing residue (COPR) incorporating industrial symbiosis	Journal of Cleaner Production	2015	95		156	162	10.1016/j.jclepro.2015.02.041
Walls J.L., Paquin R.L.	Organizational Perspectives of Industrial Symbiosis: A Review and Synthesis	Organization and Environment	2015	28	1	32	53	10.1177/1086026615575333
Golev A., Corder G.D., Giurco D.P.	Barriers to Industrial Symbiosis: Insights from the Use of a Maturity Grid	Journal of Industrial Ecology	2015	19	1	141	153	10.1111/jiec.12159
Puente M.C.R., Arozamena E.R., Evans S.	Industrial symbiosis opportunities for small and medium sized enterprises: Preliminary study in the Besaya Region (Cantabria, Northern Spain)	Journal of Cleaner Production	2015	87	C	357	374	10.1016/j.jclepro.2014.10.046

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Hein A.M., Jankovic M., Farel R., Yannou B.	A conceptual framework for eco-industrial parks	Proceedings of the ASME Design Engineering Technical Conference	2015	4				10.1115/DETC2015-46322
Yu F., Han F., Cui Z.	Reducing carbon emissions through industrial symbiosis: A case study of a large enterprise group in China	Journal of Cleaner Production	2015	103		811	818	10.1016/j.jclepro.2014.05.038
Yu F., Han F., Cui Z.	Assessment of life cycle environmental benefits of an industrial symbiosis cluster in China	Environmental Science and Pollution Research	2015	22	7	5511	5518	10.1007/s11356-014-3712-z
Tsvetkova A., Hellström M., Gustafsson M., Sjöblom J.	Replication of industrial ecosystems: The case of a sustainable biogas-for-traffic solution	Journal of Cleaner Production	2015	98		123	132	10.1016/j.jclepro.2014.08.089
Päivärinne S., Lindahl M.	Exploratory study of combining Integrated Product and Services Offerings with Industrial Symbiosis in order to improve Excess Heat utilization	Procedia CIRP	2015	30		167	172	10.1016/j.procir.2015.02.101
Ammenberg J., Baas L., Eklund M., Feiz R., Helgstrand A., Marshall R.	Improving the CO<inf>2</inf> performance of cement, part III: The relevance of industrial symbiosis and how to measure its impact	Journal of Cleaner Production	2015	98		145	155	10.1016/j.jclepro.2014.01.086
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	Journal of Cleaner Production	2015	90		211	219	10.1016/j.jclepro.2014.03.041
Li H., Dong L., Ren J.	Industrial symbiosis as a countermeasure for resource dependent city: A case study of Guiyang, China	Journal of Cleaner Production	2015	107		252	266	10.1016/j.jclepro.2015.04.089

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Kennedy C.A.	Industrial ecology and cities	Taking Stock of Industrial Ecology	2015			69	86	10.1007/978-3-319-20571-7_4
Dong L., Fujita T.	Promotion of low-carbon city through industrial and urban system innovation: Japanese experience and China's practice	World Scientific Reference on Asia and the World Economy	2015			257	279	10.1142/9789814578622_0033
Puente M.C.R., Arozamena E.R., Evans S.	Industrial symbiosis opportunities for small and medium sized enterprises: Preliminary study in the Besaya region (Cantabria, Northern Spain)	Journal of Cleaner Production	2015	87	1	357	374	10.1016/j.jclepro.2014.09.046
Cutaia L., Luciano A., Barberio G., Sbaffoni S., Mancuso E., Scagliarino C., La Monica M.	The experience of the first industrial symbiosis platform in Italy	Environmental Engineering and Management Journal	2015	14	7	1521	1533	
Aviso K.B., Chiu A.S.F., Yu K.D.S., Promentilla M.A.B., Razon L.F., Ubando A.T., Sy C.L., Tan R.R.	P-graph for optimising industrial symbiotic networks	Chemical Engineering Transactions	2015	45		1345	1350	10.3303/CET1545225
Vardanega R., Prado J.M., Meireles M.A.A.	Adding value to agri-food residues by means of supercritical technology	Journal of Supercritical Fluids	2015	96		217	227	10.1016/j.supflu.2014.09.029

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Cerdas F., Kurle D., Andrew S., Thiede S., Herrmann C., Zhiquan Y., Jonathan L.S.C., Bin S., Kara S.	Defining circulation factories - A pathway towards factories of the future	Procedia CIRP	2015	29		627	632	10.1016/j.procir.2015.02.032
Wang H., Xu X., Zhu G.	Landscape changes and a salt production sustainable approach in the state of salt pan area decreasing on the coast of Tianjin, China	Sustainability (Switzerland)	2015	7	8	10078	10097	10.3390/su70810078
Daddi T., Tessitore S., Testa F.	Industrial ecology and eco-industrial development: Case studies from Italy	Progress in Industrial Ecology	2015	9	3	217	233	10.1504/PIE.2015.073414
Deutz P., Ioppolo G.	From theory to practice: Enhancing the potential policy impact of industrial ecology	Sustainability (Switzerland)	2015	7	2	2259	2273	10.3390/su7022259
[No author name available]	Modeling and Managing Complex Systems - Proceedings of the 17th International DSM Conference	Modeling and Managing Complex Systems - Proceedings of the 17th International DSM Conference	2015					
Liu J., Nie X., Zhou C., Shi Y., Liu R.	The design of agri-industrial ecological park: A case study of Zhengzhou national economic-technological development area	Shengtai Xuebao/ Acta Ecologica Sinica	2015	35	14	4891	4896	10.5846/stxb201311242804
Graedel T.E., Lifset R.J.	Industrial ecology’s first decade	Taking Stock of Industrial Ecology	2015			3	20	10.1007/978-3-319-20571-7_1
Adiansyah J.S., Rosano M., Vink S., Keir G.	A framework for a sustainable approach to mine tailings management: Disposal strategies	Journal of Cleaner Production	2015	108		1	13	10.1016/j.jclepro.2015.07.139

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Benjamin M.F., Ubando A., Razon L., Tan R.R.	Analyzing the disruption resilience of microalgal multi-functional Bioenergy systems using dynamic inoperability input-output modeling	Chemical Engineering Transactions	2015	45		1579	1584	10.3303/CET1545264
Johnson J.A.	Dilemmas of 19th-century liberalism among German academic chemists: Shaping a national science policy from Hofmann to Fischer, 1865-1919	Annals of Science	2015	72	2	224	241	10.1080/00033790.2015.1007525
Mannino I., Ninka E., Turvani M., Chertow M.	The decline of eco-industrial development in Porto Marghera, Italy	Journal of Cleaner Production	2015	100		286	296	10.1016/j.jclepro.2015.03.054
Qu Y., Liu Y., Nayak R.R., Li M.	Sustainable development of eco-industrial parks in China: Effects of managers' environmental awareness on the relationships between practice and performance	Journal of Cleaner Production	2015	87	1	328	338	10.1016/j.jclepro.2014.09.015
Ubando A.T., Culaba A.B., Aviso K.B., Tan R.R., Cuello J.L., Ng D.K.S., El-Halwagi M.M.	Fuzzy mathematical programming approach in the optimal design of an algal bioenergy park	Chemical Engineering Transactions	2015	45		355	360	10.3303/CET1545060
Olsson L., Wetterlund E., Söderström M.	Assessing the climate impact of district heating systems with combined heat and power production and industrial excess heat	Resources, Conservation and Recycling	2015	96		31	39	10.1016/j.resconrec.2015.01.006
Li W., Cui Z., Han F.	Methods for assessing the energy-saving efficiency of industrial symbiosis in industrial parks	Environmental science and pollution research international	2015	22	1	275	285	10.1007/s11356-014-3327-4

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Feiz R., Ammenberg J., Baas L., Eklund M., Helgstrand A., Marshall R.	Improving the CO<inf>2</inf> performance of cement, part II: Framework for assessing CO<inf>2</inf> improvement measures in the cement industry	Journal of Cleaner Production	2015	98		282	291	10.1016/j.jclepro.2014.01.103
Tan R.R., Ng R.T.L., Andiappan V., Wan Y.K., Ng D.K.S.	An optimization-based cooperative game approach for allocation of costs and benefits in interplant process integration	Chemical Engineering Transactions	2015	45		403	408	10.3303/CET1545068
Ferrão P., Lorena A., Ribeiro P.	Industrial ecology and portugal’s national waste plans	Taking Stock of Industrial Ecology	2015			275	289	10.1007/978-3-319-20571-7_14
Boix M., Montastruc L., Azzaro-Pantel C., Domenech S.	Optimization methods applied to the design of eco-industrial parks: A literature review	Journal of Cleaner Production	2015	87	1	303	317	10.1016/j.jclepro.2014.09.032
Gregson N., Crang M., Fuller S., Holmes H.	Interrogating the circular economy: the moral economy of resource recovery in the EU	Economy and Society	2015	44	2	218	243	10.1080/03085147.2015.1013353
Noureldin M.M.B., El-Halwagi M.M.	Synthesis of C-H-O Symbiosis Networks	AIChE Journal	2015	61	4	1242	1262	10.1002/aic.14714
Duraccio V., Gnoni M.G., Elia V.	Carbon capture and reuse in an industrial district: A technical and economic feasibility study	Journal of CO2 Utilization	2015	10		23	29	10.1016/j.jcou.2015.02.004
Schieb P.-A., Lescieux-Katir H., Thénot M., Clément-Larosière B.	Biorefinery 2030: Future prospects for the bioeconomy	Biorefinery 2030: Future Prospects for the Bioeconomy	2015			1	123	10.1007/978-3-662-47374-0
Ferrell J.C., Shahbazi A.	County government led EIP development using municipal biomass resources for clean energy production, a case study of the Catawba County North Carolina ecocomplex	Progress in Industrial Ecology	2015	9	1	69	81	10.1504/PIE.2015.069835

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Silva C.M.A., Nielsen C.V., Alves L.M., Martins P.A.F.	Environmentally friendly joining of tubes by their ends	Journal of Cleaner Production	2015	87	1	777	786	10.1016/j.jclepro.2014.09.022
Rao P., Patil Y.	Climate resilience in natural ecosystems in india: Technology adoption and the use of local knowledge processes and systems	Handbook of Climate Change Adaptation	2015			2063	2077	10.1007/978-3-642-38670-1_95
Marinos-Kouris D., Mourtsiadis A.	Environment and recycling: Some comments on the entropy limits	Fresenius Environmental Bulletin	2015	24	3B	1158	1163	
Baas L., Hjelm O.	Support your future today: Enhancing sustainable transitions by experimenting at academic conferences	Journal of Cleaner Production	2015	98		1	7	10.1016/j.jclepro.2015.02.059
Røyne F., Berlin J., Ringström E.	Life cycle perspective in environmental strategy development on the industry cluster level: A case study of five chemical companies	Journal of Cleaner Production	2015	86		125	131	10.1016/j.jclepro.2014.08.016
Lenhart J., Van Vliet B., Mol A.P.J.	New roles for local authorities in a time of climate change: The Rotterdam Energy Approach and Planning as a case of urban symbiosis	Journal of Cleaner Production	2015	107		593	601	10.1016/j.jclepro.2015.05.026
Zhang Y., Zheng H., Yang Z., Liu G., Su M.	Analysis of the industrial metabolic processes for sulfur in the Lubei (Shandong Province, China) eco-industrial park	Journal of Cleaner Production	2015	96		127	138	10.1016/j.jclepro.2014.01.096
Sahakian M.	The social and solidarity economy: Why is it relevant to industrial ecology?	Taking Stock of Industrial Ecology	2015			205	227	10.1007/978-3-319-20571-7_10
Benjamin M.F.D., Tan R.R., Razon L.F.	A methodology for criticality analysis in integrated energy systems	Clean Technologies and Environmental Policy	2015	17	4	935	946	10.1007/s10098-014-0846-0

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Maillé M., Frayret J.-M.	Industrial Waste Reuse and By-product Synergy Optimization	Journal of Industrial Ecology	2016	20	6	1284	1294	10.1111/jiec.12403
Papathanasoglou A., Panagiotidou M., Valta K., Loizidou M.	RESEARCH ARTICLE: Institutional Barriers and Opportunities for the Implementation of Industrial Symbiosis in Greece	Environmental Practice	2016	18	4	253	259	10.1017/S1466046616000454
Wu J., Wang R., Pu G., Qi H.	Integrated assessment of exergy, energy and carbon dioxide emissions in an iron and steel industrial network	Applied Energy	2016	183		430	444	10.1016/j.apenergy.2016.08.192
Zhang B., Wang Z., Lai K.-H.	Does Industrial Waste Reuse Bring Dual Benefits of Economic Growth and Carbon Emission Reduction?: Evidence of Incorporating the Indirect Effect of Economic Growth in China	Journal of Industrial Ecology	2016	20	6	1306	1319	10.1111/jiec.12375
Ubando A.T., Culaba A.B., Aviso K.B., Tan R.R., Cuello J.L., Ng D.K.S., El-Halwagi M.M.	Fuzzy mixed integer non-linear programming model for the design of an algae-based eco-industrial park with prospective selection of support tenants under product price variability	Journal of Cleaner Production	2016	136		183	196	10.1016/j.jclepro.2016.04.143
Peter Sahay S.S., Dash S.N., Joga Rao H.	Economical benefit through industrial symbiosis: Trash to treasure: A case study in an Indian industrial area	Research Journal of Pharmaceutical, Biological and Chemical Sciences	2016	7	6	932	937	
Wu J., Qi H., Wang R.	Insight into industrial symbiosis and carbon metabolism from the evolution of iron and steel industrial network	Journal of Cleaner Production	2016	135		251	262	10.1016/j.jclepro.2016.06.103
Guo B., Geng Y., Sterr T., Dong L., Liu Y.	Evaluation of promoting industrial symbiosis in a chemical industrial park: A case of Midong	Journal of Cleaner Production	2016	135		995	1008	10.1016/j.jclepro.2016.07.006

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Pan H., Zhang X., Wang Y., Qi Y., Wu J., Lin L., Peng H., Qi H., Yu X., Zhang Y.	Emergy evaluation of an industrial park in Sichuan Province, China: A modified emergy approach and its application	Journal of Cleaner Production	2016	135		105	118	10.1016/j.jclepro.2016.06.102
Álvarez R., Ruiz-Puente C.	Development of the Tool SymbioSyS to Support the Transition Towards a Circular Economy Based on Industrial Symbiosis Strategies	Waste and Biomass Valorization	2016			1	10	10.1007/s12649-016-9748-1
Taylor C.D., Gully B., Sánchez A.N., Rode E., Agarwal A.S.	Towards materials sustainability through materials stewardship	Sustainability (Switzerland)	2016	8	10			10.3390/su8101001
Atkins M.J., Walmsley M.R.W., Walmsley T.G.	Integration of new processes and geothermal heat into a wood processing cluster	Clean Technologies and Environmental Policy	2016	18	7	2077	2085	10.1007/s10098-016-1171-6
Taddeo R.	Local industrial systems towards the eco-industrial parks: The model of the ecologically equipped industrial areas	Journal of Cleaner Production	2016	131		189	197	10.1016/j.jclepro.2016.05.051
Hodgson E., Ruiz-Molina M.-E., Marazza D., Pogrebnyakova E., Burns C., Higson A., Rehberger M., Hiete M., Gyalai-Korpos M., Lucia L.D., Noël Y., Woods J., Gallagher J.	Horizon scanning the European bio-based economy: a novel approach to the identification of barriers and key policy interventions from stakeholders in multiple sectors and regions	Biofuels, Bioproducts and Biorefining	2016	10	5	508	522	10.1002/bbb.1665

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Ren J., Liang H., Dong L., Sun L., Gao Z.	Design for sustainability of industrial symbiosis based on emergy and multi-objective particle swarm optimization	Science of the Total Environment	2016	562		789	801	10.1016/j.scitotenv.2016.04.092
Secchi M., Castellani V., Collina E., Mirabella N., Sala S.	Assessing eco-innovations in green chemistry: Life Cycle Assessment (LCA) of a cosmetic product with a bio-based ingredient	Journal of Cleaner Production	2016	129		269	281	10.1016/j.jclepro.2016.04.073
Velenturf A.P.M.	Promoting industrial symbiosis: empirical observations of low-carbon innovations in the Humber region, UK	Journal of Cleaner Production	2016	128		116	130	10.1016/j.jclepro.2015.06.027
Luciano A., Barberio G., Mancuso E., Sbaffoni S., La Monica M., Scagliarino C., Cutaia L.	Potential Improvement of the Methodology for Industrial Symbiosis Implementation at Regional Scale	Waste and Biomass Valorization	2016	7	4	1007	1015	10.1007/s12649-016-9625-y
Velenturf A.P.M., Jensen P.D.	Promoting Industrial Symbiosis: Using the Concept of Proximity to Explore Social Network Development	Journal of Industrial Ecology	2016	20	4	700	709	10.1111/jiec.12315
Renzulli P.A., Notarnicola B., Tassielli G., Arcese G., Di Capua R.	Life cycle assessment of steel produced in an Italian integrated steel mill	Sustainability (Switzerland)	2016	8	8			10.3390/su8080719

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Liu Z.-Y., Varbanov P.S., Klemeš J.J., Yong J.Y.	Recent developments in applied thermal engineering: Process integration, heat exchangers, enhanced heat transfer, solar thermal energy, combustion and high temperature processes and thermal process modelling	Applied Thermal Engineering	2016	105		755	762	10.1016/j.applthermaleng.2016.06.183
Päivärinne S., Lindahl M.	Combining Integrated Product and Service Offerings with Industrial Symbiosis – a study of opportunities and challenges	Journal of Cleaner Production	2016	127		240	248	10.1016/j.jclepro.2016.04.026
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	Sustainable Production and Consumption	2016	7		57	65	10.1016/j.spc.2016.03.001
Hu Y., Lin J., Cui S., Khanna N.Z.	Measuring Urban Carbon Footprint from Carbon Flows in the Global Supply Chain	Environmental Science and Technology	2016	50	12	6154	6163	10.1021/acs.est.6b00985
Zhang Y., Zheng H., Shi H., Yu X., Liu G., Su M., Li Y., Chai Y.	Network analysis of eight industrial symbiosis systems	Frontiers of Earth Science	2016	10	2	352	365	10.1007/s11707-015-0520-9
Felicio M., Amaral D., Esposto K., Gabarrell Durany X.	Industrial symbiosis indicators to manage eco-industrial parks as dynamic systems	Journal of Cleaner Production	2016	118		54	64	10.1016/j.jclepro.2016.01.031

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Kikuchi Y., Kanematsu Y., Ugo M., Hamada Y., Okubo T.	Industrial Symbiosis Centered on a Regional Cogeneration Power Plant Utilizing Available Local Resources: A Case Study of Tanegashima	Journal of Industrial Ecology	2016	20	2	276	288	10.1111/jiec.12347
Kikuchi Y., Kanematsu Y., Sato R., Nakagaki T.	Distributed Cogeneration of Power and Heat within an Energy Management Strategy for Mitigating Fossil Fuel Consumption	Journal of Industrial Ecology	2016	20	2	289	303	10.1111/jiec.12374
Ohnishi S., Fujii M., Ohata M., Rokuta I., Fujita T.	Efficient energy recovery through a combination of waste-to-energy systems for a low-carbon city	Resources, Conservation and Recycling	2016					10.1016/j.resconrec.2016.11.018
Liu Z., Adams M., Cote R.P., Geng Y., Li Y.	Comparative study on the pathways of industrial parks towards sustainable development between China and Canada	Resources, Conservation and Recycling	2016					10.1016/j.resconrec.2016.06.012
Kliopova I., Baranauskaite-Fedorova I., Malinauskiene M., Staniškis J.K.	Possibilities of increasing resource efficiency in nitrogen fertilizer production	Clean Technologies and Environmental Policy	2016	18	3	901	914	10.1007/s10098-015-1068-9
Liu G., Hao Y., Zhou Y., Yang Z., Zhang Y., Su M.	China's low-carbon industrial transformation assessment based on Logarithmic Mean Divisia Index model	Resources, Conservation and Recycling	2016	108		156	170	10.1016/j.resconrec.2016.02.002
Ghali M.R., Frayret J.-M., Robert J.-M.	Green social networking: Concept and potential applications to initiate industrial synergies	Journal of Cleaner Production	2016	115		23	35	10.1016/j.jclepro.2015.12.028

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
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	Resources, Conservation and Recycling	2016					10.1016/j.resconrec.2016.06.007
Zhe L., Yong G., Hung-Suck P., Huijuan D., Liang D., Tsuyoshi F.	An emergy-based hybrid method for assessing industrial symbiosis of an industrial park	Journal of Cleaner Production	2016	114		132	140	10.1016/j.jclepro.2015.04.132
Shiraki H., Ashina S., Kameyama Y., Hashimoto S., Fujita T.	Analysis of optimal locations for power stations and their impact on industrial symbiosis planning under transition toward low-carbon power sector in Japan	Journal of Cleaner Production	2016	114		81	94	10.1016/j.jclepro.2015.09.079
Park J.M., Park J.Y., Park H.-S.	A review of the National Eco-Industrial Park Development Program in Korea: Progress and achievements in the first phase, 2005-2010	Journal of Cleaner Production	2016	114		33	44	10.1016/j.jclepro.2015.08.115
Horváth G.Á., Harazin P.	A framework for an industrial ecological decision support system to foster partnerships between businesses and governments for sustainable development	Journal of Cleaner Production	2016	114		214	223	10.1016/j.jclepro.2015.05.018
Mat N., Cerceau J., Shi L., Park H.-S., Junqua G., Lopez-Ferber M.	Socio-ecological transitions toward low-carbon port cities: Trends, changes and adaptation processes in Asia and Europe	Journal of Cleaner Production	2016	114		362	375	10.1016/j.jclepro.2015.04.058
Sumabat A.K., Lopez N.S., Yu K.D., Hao H., Li R., Geng Y., Chiu A.S.F.	Decomposition analysis of Philippine CO2 emissions from fuel combustion and electricity generation	Applied Energy	2016	164		795	804	10.1016/j.apenergy.2015.12.023

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Daddi T., Iraldo F., Frey M., Gallo P., Gianfrate V.	Regional policies and eco-industrial development: The voluntary environmental certification scheme of the eco-industrial parks in Tuscany (Italy)	Journal of Cleaner Production	2016	114		62	70	10.1016/j.jclepro.2015.04.060
Jensen P.D.	The role of geospatial industrial diversity in the facilitation of regional industrial symbiosis	Resources, Conservation and Recycling	2016	107		92	103	10.1016/j.resconrec.2015.11.018
Manara P., Zabaniotou A.	Co-valorization of Crude Glycerol Waste Streams with Conventional and/or Renewable Fuels for Power Generation and Industrial Symbiosis Perspectives	Waste and Biomass Valorization	2016	7	1	135	150	10.1007/s12649-015-9439-3
Tan R.R., Andiappan V., Wan Y.K., Ng R.T.L., Ng D.K.S.	An optimization-based cooperative game approach for systematic allocation of costs and benefits in interplant process integration	Chemical Engineering Research and Design	2016	106		43	58	10.1016/j.cherd.2015.11.009
Budzianowski W.M.	A review of potential innovations for production, conditioning and utilization of biogas with multiple-criteria assessment	Renewable and Sustainable Energy Reviews	2016	54		1148	1171	10.1016/j.rser.2015.10.054
Fernandez-Mena H., Nesme T., Pellerin S.	Towards an Agro-Industrial Ecology: A review of nutrient flow modelling and assessment tools in agro-food systems at the local scale	Science of the Total Environment	2016	543		467	479	10.1016/j.scitotenv.2015.11.032
Tiu B.T.C., Cruz D.E.	An MILP model for optimizing water exchanges in eco-industrial parks considering water quality	Resources, Conservation and Recycling	2016					10.1016/j.resconrec.2016.06.005

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Iacobescu R.I., Angelopoulos G.N., Jones P.T., Blanpain B., Pontikes Y.	Ladle metallurgy stainless steel slag as a raw material in Ordinary Portland Cement production: A possibility for industrial symbiosis	Journal of Cleaner Production	2016	112		872	881	10.1016/j.jclepro.2015.06.006
Leong Y.T., Lee J.-Y., Chew I.M.L.	Incorporating Timesharing Scheme in Ecoindustrial Multiperiod Chilled and Cooling Water Network Design	Industrial and Engineering Chemistry Research	2016	55	1	197	209	10.1021/acs.iecr.5b02722
Zhao Q., Shi X.Q., Shi L.	A review of the industrial symbiosis network	Shengtai Xuebao/ Acta Ecologica Sinica	2016	36	22	7288	7301	10.5846/stxb201507301598
Albino V., Fraccascia L., Giannoccaro I.	Exploring the role of contracts to support the emergence of self-organized industrial symbiosis networks: An agent-based simulation study	Journal of Cleaner Production	2016	112		4353	4366	10.1016/j.jclepro.2015.06.070
Mantese G.C., De Piere B.A., Amaral D.C.	A procedure to validate industrial symbiosis indicators combining conceptual and empirical validation methods	Advances in Transdisciplinary Engineering	2016	4		166	175	10.3233/978-1-61499-703-0-166
Branson R.	Re-constructing Kalundborg: The reality of bilateral symbiosis and other insights	Journal of Cleaner Production	2016	112		4344	4352	10.1016/j.jclepro.2015.07.069
Stratigaki C., Loucopoulos P., Migiakis A., Zorgios Y.	Combining model-driven and capability-driven developments: A case study of industrial symbiosis	CEUR Workshop Proceedings	2016	1753		12	22	
Liu J.R., Yan Y.T., Nie X.R., Yan L.	The application of life cycle assessments to the evaluation of the environmental benefits of industrial symbioses: Research progress and challenges	Shengtai Xuebao/ Acta Ecologica Sinica	2016	36	22	7202	7207	10.5846/stxb201411032156
Boons F., Chertow M., Park J., Spekkink W., Shi H.	Industrial Symbiosis Dynamics and the Problem of Equivalence: Proposal for a Comparative Framework	Journal of Industrial Ecology	2016					10.1111/jiec.12468

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Chattopadhyay S., Kumar N., Fine C., Olivetti E.	Industrial symbiosis among small and medium scale enterprises: Case of Muzaffarnagar, India	TMS Annual Meeting	2016			173	177	
Dumoulin F., Wassenaar T., Avadí A., Paillat J.-M.	A Framework for Accurately Informing Facilitated Regional Industrial Symbioses on Environmental Consequences	Journal of Industrial Ecology	2016					10.1111/jiec.12495
[No author name available]	CEUR Workshop Proceedings	CEUR Workshop Proceedings	2016	1753				
Verguts V., Dessein J., Dewulf A., Lauwers L., Werkman R., Termeer C.J.A.M.	Industrial symbiosis as sustainable development strategy: Adding a change perspective	International Journal of Sustainable Development	2016	19	1	15	35	10.1504/IJSD.2016.073650
Lignos G., Stancari S., Bikos S., Kokossis A.	Structural and economic analysis of Industrial Symbiosis networks: a hybrid approach to assess investment opportunities	Computer Aided Chemical Engineering	2016	38		1617	1622	10.1016/B978-0-444-63428-3.50274-5
Holgado M., Morgan D., Evans S.	Exploring the scope of industrial symbiosis: Implications for practitioners	Smart Innovation, Systems and Technologies	2016	52		169	178	10.1007/978-3-319-32098-4_15
Hein A.M., Jankovic M., Farel R., Yannou B.	A data- and knowledge-driven methodology for generating ecoindustrial park architectures	Proceedings of the ASME Design Engineering Technical Conference	2016	4				10.1115/DETC2016-59171.pdf
Henkel M., Stratigaki C., Stirna J., Loucopoulos P., Zorgios Y., Migiakis A.	Extending capabilities with context awareness	Lecture Notes in Business Information Processing	2016	249		40	51	10.1007/978-3-319-39564-7_4

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Holgado M., Benedetti M., Evans S., Introna V.	Contextualisation in industrial energy symbiosis: Design process for a knowledge repository	Proceedings of the Summer School Francesco Turco	2016			139	144	
Afshari H., Gourlia J.-P., Farel R., Peng Q.	Energy symbioses in eco-industrial parks: Models and perspectives	Proceedings of the ASME Design Engineering Technical Conference	2016	4				10.1115/DETC2016-59965.pdf
Stirna J., Zdravkovic J., Henkel M., Loucopoulos P., Stratigaki C.	Modeling organizational capabilities on a strategic level	Lecture Notes in Business Information Processing	2016	267		257	271	10.1007/978-3-319-48393-1_18
Siskos I., Van Wassenhove L.N.	Synergy Management Services Companies: A New Business Model for Industrial Park Operators	Journal of Industrial Ecology	2016					10.1111/jiec.12472
Afshari H., Farel R., Peng Q.	Need for optimization under uncertainty: Designing flow exchanges in eco-industrial parks	Proceedings of the ASME Design Engineering Technical Conference	2016	4				10.1115/DETC2016-59974.pdf
Mohammed F., Biswas W.K., Yao H., Tadé M.	Identification of an environmentally friendly symbiotic process for the reuse of industrial byproduct - An LCA perspective	Journal of Cleaner Production	2016	112		3376	3387	10.1016/j.jclepro.2015.09.104
Husgafvel R., Nordlund H., Heino J., Mäkelä M., Watkins G., Dahl O., Paavola I.-L.	Use of Symbiosis Products from Integrated Pulp and Paper and Carbon Steel Mills: Legal Status and Environmental Burdens	Journal of Industrial Ecology	2016	20	5	1187	1198	10.1111/jiec.12348
Qi Y., Zhu T., Gao S., Wang J.F., Ji Y.J., Zhang M., Bu X.X.	Preliminary exploration of the Chinese industrial park’s circularization reform using key material flow analysis	Shengtai Xuebao/ Acta Ecologica Sinica	2016	36	22	7335	7345	10.5846/stxb201508151708

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
[No author name available]	3rd International Conference on Sustainable Design and Manufacturing, SDM 2016	Smart Innovation, Systems and Technologies	2016	52		1	688	
Kanematsu Y., Oosawa K., Kikuchi Y.	Agriculture	Energy Technology Roadmaps of Japan: Future Energy Systems Based on Feasible Technologies Beyond 2030	2016			405	414	10.1007/978-4-431-55951-1_27
De Souza V., Borsato M., Bloemhof J.	Designing eco-effective reverse logistics networks	Advances in Transdisciplinary Engineering	2016	4		851	860	10.3233/978-1-61499-703-0-851
Leong Y.T., Tan R.R., Aviso K.B., Chew I.M.L.	Fuzzy analytic hierarchy process and targeting for inter-plant chilled and cooling water network synthesis	Journal of Cleaner Production	2016	110		40	53	10.1016/j.jclepro.2015.02.036
Shi L., Chen W.Q.	Industrial ecology in China: Retrospect and prospect	Shengtai Xuebao/ Acta Ecologica Sinica	2016	36	22	7158	7167	10.5846/stxb201611232387
Kikuchi Y., Kanematsu Y., Okubo T.	A computer-aided scenario analysis of national and regional energy systems based on feasible technology options	Computer Aided Chemical Engineering	2016	38		1959	1964	10.1016/B978-0-444-63428-3.50331-3
Yong J.Y., Klemeš J.J., Varbanov P.S., Huisingh D.	Cleaner energy for cleaner production: Modelling, simulation, optimisation and waste management	Journal of Cleaner Production	2016	111		1	16	10.1016/j.jclepro.2015.10.062
Petek J., Glavič P., Kostevšek A.	Total Site Resource Efficiency System	Computer Aided Chemical Engineering	2016	38		2235	2240	10.1016/B978-0-444-63428-3.50377-5
Yazan D.M., Romano V.A., Albino V.	The design of industrial symbiosis: An input-output approach	Journal of Cleaner Production	2016					10.1016/j.jclepro.2016.03.160
Kuznetsova E., Zio E., Farel R.	A methodological framework for Eco-Industrial Park design and optimization	Journal of Cleaner Production	2016					10.1016/j.jclepro.2016.03.025

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Notarnicola B., Tassielli G., Renzulli P.A.	Industrial symbiosis in the Taranto industrial district: Current level, constraints and potential new synergies	Journal of Cleaner Production	2016					10.1016/j.jclepro.2016.02.056
Szabó S., Bódis K., Kougias I., Moner-Girona M., Jäger-Waldau A., Barton G., Szabó L.	A methodology for maximizing the benefits of solar landfills on closed sites	Renewable and Sustainable Energy Reviews	2017	76		1291	1300	10.1016/j.rser.2017.03.117
Fraccascia L., Giannoccaro I., Albino V.	Rethinking Resilience in Industrial Symbiosis: Conceptualization and Measurements	Ecological Economics	2017	137		148	162	10.1016/j.ecolecon.2017.02.026
Wu J., Guo Y., Li C., Qi H.	The redundancy of an industrial symbiosis network: A case study of a hazardous waste symbiosis network	Journal of Cleaner Production	2017	149		49	59	10.1016/j.jclepro.2017.02.038
Wang D., Li J., Wang Y., Wan K., Song X., Liu Y.	Comparing the vulnerability of different coal industrial symbiosis networks under economic fluctuations	Journal of Cleaner Production	2017	149		636	652	10.1016/j.jclepro.2017.02.137
Desrochers P., Szurmak J.	Long distance trade, locational dynamics and by-product development: Insights from the history of the American cottonseed industry	Sustainability (Switzerland)	2017	9	4			10.3390/su9040579
Sun L., Spekkink W., Cuppen E., Korevaar G.	Coordination of industrial symbiosis through anchoring	Sustainability (Switzerland)	2017	9	4			10.3390/su9040549
Hein A.M., Jankovic M., Feng W., Farel R., Yune J.H., Yannou B.	Stakeholder power in industrial symbioses: A stakeholder value network approach	Journal of Cleaner Production	2017	148		923	933	10.1016/j.jclepro.2017.01.136

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
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	Resources, Conservation and Recycling	2017	119		78	88	10.1016/j.resconrec.2016.06.007
Tiu B.T.C., Cruz D.E.	An MILP model for optimizing water exchanges in eco-industrial parks considering water quality	Resources, Conservation and Recycling	2017	119		89	96	10.1016/j.resconrec.2016.06.005
Fraccascia L., Giannoccaro I., Albino V.	Efficacy of landfill tax and subsidy policies for the emergence of industrial symbiosis networks: An agent-based simulation study	Sustainability (Switzerland)	2017	9	4			10.3390/su9040521
Gabriel M., Schöggl J.-P., Posch A.	Early front-end innovation decisions for self-organized industrial symbiosis dynamics-A case study on lignin utilization	Sustainability (Switzerland)	2017	9	4			10.3390/su9040515
Saraceni A.V., Resende L.M., de Andrade Júnior P.P., Pontes J.	Pilot testing model to uncover industrial symbiosis in Brazilian industrial clusters	Environmental Science and Pollution Research	2017	24	12	11618	11629	10.1007/s11356-017-8794-y
Daddi T., Nucci B., Iraldo F.	Using Life Cycle Assessment (LCA) to measure the environmental benefits of industrial symbiosis in an industrial cluster of SMEs	Journal of Cleaner Production	2017	147		157	164	10.1016/j.jclepro.2017.01.090
Mauthoor S.	Uncovering industrial symbiosis potentials in a small island developing state: The case study of Mauritius	Journal of Cleaner Production	2017	147		506	513	10.1016/j.jclepro.2017.01.138

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
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	10.1016/j.enpol.2016.12.013
Serdar M., Biljecki I., Bjegović D.	High-performance concrete incorporating locally available industrial by-products	Journal of Materials in Civil Engineering	2017	29	3			10.1061/(ASCE)MT.1943-5533.0001773
Yedla S., Park H.-S.	Eco-industrial networking for sustainable development: review of issues and development strategies	Clean Technologies and Environmental Policy	2017	19	2	391	402	10.1007/s10098-016-1224-x
Ubando A.T., Aguilar K.D.T.	Fuzzy quadratic programming model for the optimal design of an algal bioenergy park under optimal price markdown percentage	IEEE Region 10 Annual International Conference, Proceedings/TENCON	2017			936	941	10.1109/TENCON.2016.7848142
Leong Y.T., Lee J.-Y., Tan R.R., Foo J.J., Chew I.M.L.	Multi-objective optimization for resource network synthesis in eco-industrial parks using an integrated analytic hierarchy process	Journal of Cleaner Production	2017	143		1268	1283	10.1016/j.jclepro.2016.11.147
Ceglia D., Abreu M.C.S.D., Da Silva Filho J.C.L.	Critical elements for eco-retrofitting a conventional industrial park: Social barriers to be overcome	Journal of Environmental Management	2017	187		375	383	10.1016/j.jenvman.2016.10.064
Winans K., Kendall A., Deng H.	The history and current applications of the circular economy concept	Renewable and Sustainable Energy Reviews	2017	68		825	833	10.1016/j.rser.2016.09.123
Yap N.T., Devlin J.F.	Explaining Industrial Symbiosis Emergence, Development, and Disruption: A Multilevel Analytical Framework	Journal of Industrial Ecology	2017	21	1	6	15	10.1111/jiec.12398

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Ohnishi S., Dong H., Geng Y., Fujii M., Fujita T.	A comprehensive evaluation on industrial & urban symbiosis by combining MFA, carbon footprint and emergy methods—Case of Kawasaki, Japan	Ecological Indicators	2017	73		315	324	10.1016/j.ecolind.2016.10.016
Taddeo R., Simboli A., Ioppolo G., Morgante A.	Industrial symbiosis, networking and innovation: The potential role of innovation poles	Sustainability (Switzerland)	2017	9	2			10.3390/su9020169
Wang Q., Deutz P., Chen Y.	Building institutional capacity for industrial symbiosis development: A case study of an industrial symbiosis coordination network in China	Journal of Cleaner Production	2017	142		1571	1582	10.1016/j.jclepro.2016.11.146
Zhang C., Romagnoli A., Zhou L., Kraft M.	Knowledge management of eco-industrial park for efficient energy utilization through ontology-based approach	Applied Energy	2017					10.1016/j.apenergy.2017.03.130
Fan Y., Qiao Q., Fang L., Yao Y.	Emergy analysis on industrial symbiosis of an industrial park – A case study of Hefei economic and technological development area	Journal of Cleaner Production	2017	141		791	798	10.1016/j.jclepro.2016.09.159
Sharib S., Halog A.	Enhancing value chains by applying industrial symbiosis concept to the Rubber City in Kedah, Malaysia	Journal of Cleaner Production	2017	141		1095	1108	10.1016/j.jclepro.2016.09.089
Couto Mantese G., Capaldo Amaral D.	Comparison of industrial symbiosis indicators through agent-based modeling	Journal of Cleaner Production	2017	140		1652	1671	10.1016/j.jclepro.2016.09.142
Fraccascia L., Albino V., Garavelli C.A.	Technical efficiency measures of industrial symbiosis networks using enterprise input-output analysis	International Journal of Production Economics	2017	183		273	286	10.1016/j.ijpe.2016.11.003

Author Name(s)	Title	Source Title	Year	Vol.	Issue	P. Start	P. End	Doi
Tseng M.-L., Bui T.-D.	Identifying eco-innovation in industrial symbiosis under linguistic preferences: A novel hierarchical approach	Journal of Cleaner Production	2017	140		1376	1389	10.1016/j.jclepro.2016.10.014
Kim H.-W., Ohnishi S., Fujii M., Fujita T., Park H.-S.	Evaluation and Allocation of Greenhouse Gas Reductions in Industrial Symbiosis	Journal of Industrial Ecology	2017					10.1111/jiec.12539
Halstenberg F.A., Lindow K., Stark R.	Utilization of Product Lifecycle Data from PLM Systems in Platforms for Industrial Symbiosis	Procedia Manufacturing	2017	8		369	376	10.1016/j.promfg.2017.02.047
Dong L., Wang Y., Scipioni A., Park H.-S., Ren J.	Recent progress on innovative urban infrastructures system towards sustainable resource management	Resources, Conservation and Recycling	2017					10.1016/j.resconrec.2017.02.020
Wang X., Shi X.Q.	A review of industrial ecology based on GIS	Shengtai Xuebao/ Acta Ecologica Sinica	2017	37	4	1346	1357	10.5846/stxb201606301326
Oguntoye O., Evans S.	Framing Manufacturing Development in Africa and the Influence of Industrial Sustainability	Procedia Manufacturing	2017	8		75	80	10.1016/j.promfg.2017.02.009
Hein A.M., Yannou B., Jankovic M., Farel R.	Towards an automatized generation of rule-based systems for architecting eco-industrial parks	Smart Innovation, Systems and Technologies	2017	65		691	699	10.1007/978-981-10-3518-0_60
Dias G.M., Ayer N.W., Khosla S., Van Acker R., Young S.B., Whitney S., Hendricks P.	Life cycle perspectives on the sustainability of Ontario greenhouse tomato production: Benchmarking and improvement opportunities	Journal of Cleaner Production	2017	140		831	839	10.1016/j.jclepro.2016.06.039
Medina-González S., Graells M., Guillén-Gosálbez G., Espuña A., Puigjaner L.	Systematic approach for the design of sustainable supply chains under quality uncertainty	Energy Conversion and Management	2017					10.1016/j.enconman.2017.02.060

Author Name(s)	**Title**	**Source Title**	**Year**	**Vol.**	**Issue**	**P. Start**	**P. End**	**Doi**
Malinauskiene M., Kliopova I., Hugi C., Staniškis J.K.	Geostrategic Supply Risk and Economic Importance as Drivers for Implementation of Industrial Ecology Measures in a Nitrogen Fertilizer Production Company	Journal of Industrial Ecology	2017					10.1111/jiec.12561
Deutz P., Baxter H., Gibbs D., Mayes W.M., Gomes H.I.	Resource recovery and remediation of highly alkaline residues: A political-industrial ecology approach to building a circular economy	Geoforum	2017					10.1016/j.geoforum.2017.03.021

APPENDIX-II

TOP TEN COUNTRIES IN INDUSTRIAL SYMBIOSIS RESEARCH WITH INDUSTRIAL GROWTH INDICATORS

Countries	No. of Papers	Annual Industrial Growth rate	Industrial production in Price (million US$)
China	85	6.10%	474,000
USA	49	0.10%	351,600
UK	49	3.10%	38,500
Italy	34	1.80%	39,400
Japan	27	2.00%	138,000
Netherland	21	3.10%	13,100
Philippines	21	7.20%	9,920
Australia	19	-1.60%	369,400
Canada	19	4.80%	22,200
France	19	1.30%	30,900

APPENDIX-III

LIST OF IE FOCUSED AND RELATED COURSES OFFERED IN DAIs (2017)

DAI	Level of Study	Program	Course Title
International Islamic University, Islamabad	Graduate	MS Environmental Science	Industrial Ecology Cleaner Production Technologies Green Economy
	Undergraduate	BS Environmental Science	Pollution Control Technologies
National University for Science and Technology, Islamabad	Post Graduate	PhD Chemical Engineering	Cleaner Production Technologies
	Graduate	MS Chemical Engineering	Green Process Engineering Cleaner Production Technologie
		MS Process Engineering	Green Process Engineering
		MS Design and Manufacturing	Product Life Cycle Management
	Under Graduate	BS Environmental Engineering	Cleaner Production Technologies
		BS Industrial Design	Biomimicry
Quaid-e-Azam University, Islamabad	Undergraduate	MSc Environmental Science	Integrated Waste Management
Bahudin Zakriya University Multan	Undergraduate	BS Environmental Science	Pollution Control Technologies
Fatima Jinnah Women University, Rawalpindi	Undergraduate	BS Environmental Science	Pollution Control Technologies
Government College University, Faisalabad	Grauate	MS Environmental Science	Industrial Ecology Cleaner Production Technologies
	Undergraduate	MSc Environmental Science	Cleaner Production Technologies
Government College for Women, Faisalabad	Grauate	MS Environmental Science	Industrial Ecology Cleaner Production Technologies
	Undergraduate	MSc Environmental Science	Cleaner Production Technologies
Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi	Grauate	MS Environmental Science	Cleaner Production Technologies Pollution Control Technologies

University of Agriculture Faisalabad	Undergraduate	BS Environmental Engineering	Cleaner Production Technologies
University of Engineering and Technology, Lahore	Undergraduate	BS Environmental Engineering	Cleaner Production Technologies
University of Gujrat, Gujrat	Grauate	MS Environmental Science	Industrial Ecology Cleaner Production Technologies
University of the Punjab, Lahore	Graduate	MS Environmental Science	Integrated Solid Waste Management and Life Cycle Assessment
	Undergraduate	BS Agriculture Engineering	Agro Industrial Management
Sindh Madresatul Islam University, Karachi	Graduate	MS Environmental Science	Industrial Ecology
	Undergraduate	BS Environmental Science	Cleaner Production Technologies
University of Sindh Jamshoro	Graduate	MS Environmental Science	Environmental Pollution Control Technologies
University of Haripur, Haripur	Graduate	MS Environmental Science	Cleaner Production Technologies
University of Balochistan, Quetta	Graduate	MS Environmental Science	Cleaner Production Technologies
Forman Christian College, Lahore	Graduate Undergraduate	MS Environmental Science BS Environmental Science	Cleaner Production Technologies Green Chemistry
Univeristy of Management and Technology, Lahore	Graduate	MS Environmental Science	Green Economy Industrial Ecology Cleaner Production Technologies
Institute of Business Management, Karachi	Post Graduate	PhD Energy and Environmental Management	Advances in Green Technology and Management

APPENDIX-IV

POST-GRADUATE RESEARCH IN RELEVANCE TO INDUSTRIAL ECOLOGY

S. No.	Researcher	Institution	Topics
1	(Ahmad, 1996)	Quaid-E-Azam University, Islamabad	Pollution studies of industrial wastes and investigation of remedial measures for its effective control
2	(Qureshi, 2008)	Mehran University of Engineering and Technology, Jamshoro	Production of granular activated carbon from agricultural waste for sugar decolonization & water treatment.
3	(Sharif, 2009)	University of Agriculture, Faisalabad	Rice industrial by-products management for oil extraction and value-added products
4	(Iqbal, 2010)	National College of Business Administration and Economics, Lahore	Conversion and utilization of municipal soil waste into stable, mature, enriched compost and its evaluation
5	(Hussain, 2010)	Bahauddin Zakariya University, Multan	Solid waste management into bio-fertilizer and pollution control
6	(Durrani, 2010)	Mehran University of Engineering and Technology Jamshoro	Strategies for vehicle waste- oil management in Pakistan
7	(Saleem, 2012)	Foundation University, Islamabad	Natural environmental strategies by corporation

APPENDIX-V

TEMPLETE OF EMAIL

I am Nadia Akhtar, PhD Scholar at Department of Environmental Science International Islamic University. I am writing to you because we have received funding from the Higher Education Commission of Pakistan to work with businesses and institutions in I-9/I-10 Industrial Area of Islamabad to help them identify potential partnerships with other businesses and institutions for the reuse of currently unused byproducts. These would include materials, water, and energy.

For example, you might have a byproduct that somebody else could use, or you might be able to use something that somebody else is currently throwing in a landfill.

Businesses and other facilities in the region are also being contacted while some other already agreed to participate in this project by providing us with information about their unused outputs and their inputs that could possibly come from somebody else. I am writing to find out whether you would be interested in participating also.

If you are interested in participating, we will send you a survey booklet to fill out. You would hang onto this survey booklet, and we would contact you in about a week to set up an appointment to come out to your office. We would meet with you to go over the survey and make sure we understand it before we take it away and try to match you up with other facilities. This wouldn’t take long, and there is no cost to you.

Would you be interested in participating? Please reply to this email with name of the person to be contacted and his/her contact details.

APPENDIX-VI

SURVEY BOOKLET

Survey of Industrial Inputs and Outputs for Assessment of By-product Exchange Potential in Industrial Area of Islamabad

Dear Respondent,

Thank you for taking time to complete this questionnaire. The purpose of this questionnaire is to gather information on potential utilisation of industrial waste, instead of dumping it. Information gather through this questionnaire will be utilized for Ph.D. Thesis on "*Assessment of By-product Exchange Potential for Industrial Symbiosis in Islamabad".* Industrial symbiosis is an emerging field of study which is defined as a relationship between two urrelated industries, where waste from one indsutry can be utlized as input for other industry. Worldwide companies are adopting to maximise their profits and as an alternative to dumping.

Researchers understand the need for confidentiality of this data. Data in raw form will only be disclosed to researcher and supervisor. The questionnaire is divided into six parts. Please answer all questions. Please write N/A for questions not relevant to your industry).

Your contribution is highly appreciable for us. In case of any query please contact

Nadia Akhtar

Research Associate (PhD Scholar)

Department of Environmental Science

International Islamic University, Islamabad

Phone No: 92-332-7511433

Email: nadia@iiu.edu.pk

Section I: Business Details

Name of Industry:---

Address:---

Contact Person: (Phone No., Email)--

Number of Employees (Full Time: ------------------------------ Part Time:----------)

Annual Production: --

Section II: Inputs and Outputs

Please mark √ for your inputs and mention annual quantities of inputs. If annual quantities are not known please put a question mark on the relevant input.

	Inputs	Quantity	Units
7.1 Energy			
7.1.1	Electricity		(kWh)
7.1.2	Petrol		L
7.1.3	Diesel		L
7.1.4	Oil		L
7.1.5	Gas		L
7.1.6	LPG		Kg
7.1.7	Coal		Tonnes
7.1.8	Biomass		Tonnes
7.2 Water			
7.2.1	Supply Water		m^3
7.2.2	Groundwater		m^3
7.2.3	Hot Water/Steam		m^3
7.2.4	Treated Water		m^3
7.3 Metals			
7.3.1	Iron		Tonnes
7.3.2	Stainless Steel		Tonnes
7.3.3	Steel		Tonnes
7.3.4	Aluminum		Tonnes
7.3.5	Other		Tonnes
7.4 Plastic			
7.4.1	ABS		Tonnes

	Inputs (Contd.)	Quantity	Unit
7.8 Alkalis			
7.8.1	Calcium based		
7.8.2	Sodium-based		
7.8.3	Boron-based		
7.8.4	Other Alkalis		
7.9 Solvents			
7.9.1	Halogenated		
7.9.2	Non-halogenated		
7.10 Ink & Dyes			
7.10.1	Thinners		L
7.10.2	Hydrogen peroxide		
7.10.3	Paints		L
7.10.4	Developers/Binde r		L
7.10.5	Ink/dyes		L
7.10.6	Absorbents		L
7.11 Oil & lubricants			
7.11.1	Engine Oil		L
7.11.2	Transmission Oil		L
7.11.3	Other Oil		L
7.11.4	Coolant		L
7.11.5	Lubricants		m^3
7.12 Other			

7.4.2	HDPE		Tonnes
7.4.3	LDPE		Tonnes
7.4.4	PET		Tonnes
7.4.5	PP		Tonnes
7.4.6	Mixed Plastics		Tonnes
7.4.7	Other plastics		Tonnes
7.5 Organic Compounds			
7.5.1	Fatty Acids		tonnes
7.5.2	Carbohydrates		tonnes
7.5.3	Activated Carbon		tonnes
7.5.4	Other Organics		tonnes
7.6 Inorganic Compounds			
7.6.1	Alumina Based		tonnes
7.6.2	Calcium based		tonnes
7.6.3	Sodium Based		tonnes
7.6.4	Clay or carbon		tonnes
7.6.5	Other		tonnes
7.7 Acids			
7.7.1	Sulfuric		tonnes
7.7.2	Phosphoric		tonnes
7.7.3	Chromic		tonnes
7.7.4	Hydrochloric		tonnes
7.7.5	Nitric		tonnes
7.7.6	Hydroflouric		tonnes
7.7.7	Acetic		tonnes
7.7.8	Any other		tonnes

7.12.1	Compressed Air		
7.12.2	Paper/cardboards		
7.12.3	Rubber		
7.12.4	Batteries		
7.12.5	Glass		
7.12.6	Packing material		
7.12.7	Soaps/detergents		
7.12.8	Wood Products		tonnes
7.12.9	Rags		
7.12.10	Cotton		
7.12.11	Fibers		
7.12.12	Tyres		
7.12.13	Concrete		
7.12.14	Sand/gravel		
7.12.15	Any Other		

Wastes generated (outputs)-solid and liquid

Type of Waste	Quantity	Method of Disposal	Name of Waste Collector	Frequency of Collection	Cost incurred
Solid Waste (tonnes/annum)					
Paper/Card Board					
Other packaging waste (specify)					
Rubber					
Metal (Specify)					
Plastic (Specify)					
Glass					
Oil Filters					
Wood Products					
Empty Drums/Containers					
Rags					
Batteries					
Tyres					
Pre-manufactured Components					
Slag					
Air Filter Dust					
Mill Scale					
Cuttings/scraps					
Marble Dust Powder					
Slurry					
Sludge					
Biodegradable Waste (Specify)					
Other					
Liquid Waste (Litres/annum)					
Wastewater					
Hot Water					
Thinners/Solvents					
Waste Oil					
Transmission Oil					
Other Oil					
Coolant					

Ink/Dye					
Sludge					
Other					

Section III- Waste Exchange

Are you aware of the waste management option known as "Waste Exchange" or "by-product exchange" (waste from one business may be used as raw materials by another business)-

NO (if no go to question 10 or 11)

You come to know about waste exchange options through:

a) Governmental Authorities
b) Industrial Associations
c) Waste Recyclers
d) Any other (Specify)--

If you are a consumer

Type of waste being consumed	**From where you accept these waste**	**What is the purpose for using waste**	**Quantity Required**	**Unit Cost**

If you are a supplier

Type of waste being supplied	**To whom you are supplying**	**For what purpose it's being used**	**Quantity Supplied**	**Income/unit**

Section IV- Waste Exchange-Development of the process

What is the mechanism of dealings between you and your waste exchange partner (either consumer or supplier) were consolidated?-

a) Contract (legal)
b) Mutual Understanding
c) Any other (please specify)
10. What, in your opinion, are the constraints you face with waste exchange?
a) Financial
b) Legislative/regulatory
c) Any other (please specify):

Do you see a potential for waste from your industry being reused by other business?

[Yes] [No]

If yes, what type of activity is best suited to use the waste from your industry?

Do you see a potential to use wastes from other activity as raw materials? [No]

[Yes] [No]

If yes, what waste will you use and what type of businesses generate it?

--In your opinion what are the opportunities available to develop such waste exchanges between industries?

In your opinion what are the factors which hinder the development of waste exchange synergies?

Thank you for your time and effort in answering this questionnaire

APPENDIX-VII

LIST OF INDUSTRIES IN INDUSTRIAL AREA, ISLAMABAD

Sr. No.	PSIC Code	Products	Company Name	Owner Name	Lat	Long	Address	Email	Website	Certification
1.	C-25112	Aluminium manufacturing	Pak Al-Tech Aluminium	Mr. Naeem Ahmed	33°39'22.43" N	73° 2'20.56"E	Plot No. 43, Street No. 2, I-10/3, Islamabad	al-tech18@yahoo.com		
2.	G-4520	Automobile Workshop	Auto Club (Workshop)		33°39'16.37" N	73° 2'40.46"E	Plot No. 214, I-10/3, Industrial Area, Islamabad			
3.	C-1071	Bakery Products	Triways Food Industries	Ch. Muhammad Jamil	33°39'19.66" N	73° 2'28.20"E	Plot No. 20, Street No. 3, I-10/3, Islamabad	triways_food@hotmail.com		
4.	C-1071	Baking Industry	Liaqat Karkhana (Tehzeeb Bakers)		33°39'19.66" N	73° 2'11.95"E	Plot No. 60 E, Street No. 7, I-10/3, Industrial Area, Islamabad			
5.	C-26302	Defence Electronics	RWR Pvt. Ltd.	Mr. Abdul Shakoor Amjad	33°39'46.26" N	73° 3'15.55"E	Plot No. 219/A, Street No.7, I-9/2, Industrial Area, Islamabad.	amjad@rwlimited.com		

6.	C-26302	Design & Manufactuirng of Electronic assesmblies for defence & telecommunication quipment	Zeeshan Electronics	Mr. Ziauddin Sheikh	33°39'19.65" N	73° 2'3.09"E	Plot No. 62 Khayaban-E-Johar, I-10/3 Industrial Area Islamabad	zia@zeeshanelectronics.com	http://www.zeeshanelectronics.com/	
7.	C-2219	Cooling system Rubber parts	International Ploymer Industries	Mr. M Aslam Bhutta	33°39'32.76" N	73° 2'50.73"E	Plot No. 49, Street No 10, I-9/2 Industrial Area Islamabad	polymer@apollo.net.pk	http://www.ipitractorparts.com/	ISO 9001
8.	C-10611	Flour and Processing Mills	Rizwan Flour Mills				I-10/3 Islamabad	-		
9.	C-10611	Flour and Processing Mills	Akbar Flour & General Mills	Mian Ahmad Raza	33°39'5.19"N	73° 2'4.05"E	Plot No. 89, Street No. 7, I-10/3, Industrial Area Islamabad			
10.	C-10611	Flour and Processing Mills	Mukhtar Flour & General Mills	Mr. Fahad Farooq	33°39'3.43"N	73° 2'23.13"E	Plot No. 147, Street No. 9, I-10/3, Industrial Area, Islamabad	mukhtar_flour_millhotmail.com		
11.	C-10611	Flour Mill	Al-azeem Flour & General Mills	Mr. Sohail Irfan Abbasi	33°39'7.97"N	73° 2'10.14"E	Plot No. 95, Street No. 7, I-10/3, Islamabad	sohail_abi@hotmail.com		
12.	C-10611	Flour Mill	Al-Faisal Flour & General Mills	Mr. Rashid Akram	33°39'1.97"N	73° 2'11.23"E	Plot No. 124-125, Street 8, I-10/3, Islamabad	ahmedaziz28@hotmail.com		
13.	C-10611	Flour mill	New Al-Hilal Flour Mills Pvt. Ltd	Mr. Ejaz Rasool Bhutta	33°39'35.80" N	73° 3'29.51"E	Plot No. 345-346, Street No. 5, I-9, Industrial Area, Islamabad	newalhilafm@gmail.com		

14.	C-10611	Flour Mill	New Arshad Flour Mills	Sheikh Nadeem Akram	33°39'39.82" N	73° 3'18.61"E	Plot No. 262-263, I-9, Industrial Area, Islamabad			
15.	C-10611	Flour Mill	New Noor Flour & General Mills	Mr. Khairullah Khan	33°39'8.33"N	73° 2'12.19"E	Plot No. 98-99, I-10/3, Industrial Area Islamabad			
16.	C-10611	Flour Mill	Rawal International Flour & General Mills Pvt. Ltd	Raja Majid Rehman	33°39'34.58" N	73° 2'28.13"E	Plot No. 344, Stree No.5, I-9/3, Industrial Area Islamabad	rajamajid64@gmail.com		
17.	C-10611	Flour Mill	Waqar Flour & General Mills Pvt. Ltd	Mr. Ibrar Ahmad	33°39'32.68" N	73° 3'23.89"E	Plot No. 341, I-9, Industrial Area, Islamabad			
18.	C-10611	Flour Mill/Processing	Nafees Flour & General Mills	Mr. Muhammad Tahir	33°39'49.88" N	73° 3'42.61"E	Plot No. 413, I-9, Industrial Area Islamabad			
19.	C-10611	Flour Milling	Islamabad Sunny Flour Mills Pvt. Ltd.	Mr. Wajid Abdullah	33°38'58.87" N	73° 2'18.74"E	Plot No. 162, Street No. 9, I-10/3, Industrial Area Islamabad	sunnyfisb@gmail.com	http://www.sunnyflour.com/index.htm	ISO 9001:2008, HACCP /ISO22000
20.	C-10611	Flour Milling	Al-Sajjad Flour Mills	Malik Aqeel Ahmad	33°39'54.91" N	73° 3'38.83"E	Plot No. 408, I-9/3, Industrial Area, Islamabad	alsajjadflourmills@gmail.com		
21.	C-10611	Flour Milling & Processing	Khawaja Bros Flour & General Mills (Pvt) Ltd.	Kh. Imran Hameed Qadri	33°39'38.63" N	73° 3'36.32"E	Plot No. 369-370, Street No.5, I-9/3, Industrial Area Islamabad			
22.	C-10611	Flour Milling & Processing	New Fine Flour & General Mills	Sheikh Muhammad Nadeem	33°39'38.80" N	73° 3'35.68"E	Plot No. 368, Street No. 5, Sector I-9, Industrial Area Islamabad	fine_eng@yahoo.com		

23.	C-10611	Flour Milling & Processing	Noor Flour & General Mill	Mr. Abdul Rehman Khan	33°39'23.06" N	73° 2'11.56"E	Plot No. 59-A & B, I-10/3, Industrial Area Islamabad	safeerkhan64@yahoo.com		
24.	C-10611	Flour Milling & Processing	Saeed Flour Mills	Mr. Sajid Saeed	33°39'28.30" N	73° 3'15.92"E	Plot No.269, Street No.6, I-9/3, Industrial Area, Islamabad			
25.	C-10611	Flour Milling and processing	Al-Qaim Flour and General Mills	Mr. Muhammad Raza	33°39'2.43"N	73° 2'11.99"E	Plot No. 123, Street No. 8, I-10/3, Industrial Area, Islamabad	alqaimmills@yahoo.com		
26.	C-10611	Flour Milling and processing	Bami Khan Flour and General Mills Pvt. Ltd.	Mr. Sanaullah Khan	33°39'54.16" N	73° 3'36.77"E	Plot No. 407, I-9/3, Industrial Area Islamabad	bamikhan@hotmail.com		
27.	C-10611	Flour Milling and processing	Chaudhry Flour Mills Pvt. Ltd.	Mr. Tariq Junaid	33°39'34.61" N	73° 3'25.41"E	Plot No. 342-343, Street No. 5, I-9, Industrial Area Islamabad	junaid_888@hotmail.com		
28.	C-10611	Flour Milling and processing	Esmail Flour Mills Pvt. Ltd.	Sheikh Muhammad Ijaz	33°40'0.04"N	73° 3'22.78"E	Plot No. 286-287, I-9, Industrial Area, Islamabad	esmailflourmills@yahoo.co.uk		
29.	C-10611	Flour Milling and processing	Islamabad Flour and General Mills	Mr. M. Afzal Rashid Bhatti	33°39'48.60" N	73° 3'32.96"E	Plot No. 300-302, I-9, Industrial Area, Islamabad.			
30.	C-10611	Flour milling	Rehmat Flour & General Mills	Mr. Shaukat Ali	33°39'20.63" N	73° 2'29.44"E	Plot No. 5-M, Street No.1, I-10/3, Industrial Area Islamabad	alkarim.trading@gmail.com		
31.	C-10611	Flour Milling/processing	United Flour Mills	Mr. Khalid (Late)	33°39'49.73" N	73° 3'12.98"E	Plot No. 175-178, Street No.2, I-9, Industrial Area, Islamabad	zeeshan@unitedsol.net		

32.	C-10611	Flour Mills	Al-Kausar Flour and General Mills	Mr. Muhammad Akram	33°39'31.95" N	73° 2'46.79"E	St. 12, Plot No. 46, 47, 48, I-9, Industrial Area, Islamabad	alkausarmills@yahoo.com		
33.	C-10611	Flour Mills	Sihala Flour & General Mills Pvt. Ltd	Sh.Tariq Sadiq	33°39'59.90" N	73° 3'34.43"E	Plot NO. 400-403, I-9, Industrial Area, Islamabad.	sihalaflour@gmail.com		
34.	C-10611	Flour Mills/Processing	Al-Imran Roller Flour Mills	Kh. Muhammad Imran	33°39'39.60" N	73° 3'40.04"E	Plot No. 371, 373, Street No. 5, I-9/3, Industrial Area Islamabad	57m9008@yahoo.com		
35.	C-10611	Flour processin	Capital flour and General Mills		33°39'3.24"N	73° 2'25.33"E	Plot No. 148, Street No. 9, I-10/3, Industrial Area, Islamabad			
36.	C-10611	Flour Processing	Kashmir Flour and General Mills	Ch. Mukhtar Ahmed	33°39'36.32" N	73° 3'34.17"E	Plot No. 333-334, I-9 Industrial Area, Islamabad	mukhtarahmad.ak@gmail.com		
37.	C-10611	Flour Processing	Mehboob Flour and General Mills		33°40'4.02"N	73° 2'32.51"E	Plot No. 397, I-9, Industrial Area, Islamabad			
38.	C-10611	Flour Processing	Ismail Flour Mills Pvt.limited		33°40'1.91"N	73° 3'22.59"E	Plot No. 286,287, I-9, Industrial Area, Islamabad			
39.	C-10611	Flour Processing	Sarwar flour and Mills		33°39'13.69" N	73° 2'6.23"E	Plot No. 81 C, Street No. 6, I-10/3, Industrial Area, Islamabad			
40.	C-10611	Flour Processing	Hashim Sharif Flour Mills Pvt (Ltd)		33°39'25.52" N	73° 2'25.04"E	Plot No. 3 E, Street No. 1, I-10/3, Industrial Area, Islamabad			
41.	C-10611	Flour Processing	Gul Noor Flour & General Mills	Mr. Faiz Ullah Khan	33°39'4.59"N	73° 2'6.30"E	Plot No. 100-101, Street No. 7,			

							I-10/3, Industrial Area, Islamabad			
42.	C-10713	Baked Products	United Biscuit Company		33°39'39.12" N	73° 2'31.36"E	Plot No. 349,350,351.352, I-9/3 Industrial Area, Islamabad			
43.	C-24108	Steel Pipes	Victory Pipe Industries	Ch. Waheed-ud-Din	33°39'39.34" N	73° 3'26.94"E	Plot No. 330, Street No. 4, I-9/3, Islamabad	info@victorypipe.com.pk		
44.	C-2710	Electric motors, thermostat etc	Tesla Industries	Mr. Aamir Hussain	33°39'15.01" N	73° 2'11.32"E	Plot No. 81-G, Street No. 6, I-10/3, Islamabad	info@tels-tech.com		
45.	C-29301	Manufacturing of autoparts, wheelhub	Rastgar Engineering Co (PVT) Ltd	Mr. Imtiaz Ali Rastgar	33°39'42.78" N	73° 3'21.63"E	Plot No. 304-307, Street No. 03, I-9/3, Industrial Area Islamabad	info@rastgar.com	http://www.rastgar.com/wheel-hubs/	ISO14001, OHSAS 18001, The Global Compact, Gender Equity
46.	H-49238	Transportation	Farazim Resource Pvt. Ltd. (KKC), Provides Transport	Mr. Imran Ali Khadim	33°39'14.31" N	73° 2'57.24"E	Plot No. 127 A, I-9/2, Industrial Area, Islamabad	accounts@kkc.com.pk	http://www.kkc.com.pk/index.php	
47.	C-24108	Steel Pipes	Shaheen Pipe Industries	Mr. Mansoor Ahmad Khan	33°39'29.00" N	73° 2'39.17"E	Plot No. 9, I-9/2, Industrial Area, Islamabad	shaheenpipe@gmail.com		
48.	C-23961	Marble Processing	Swat Marbles		33°39'24.68" N	73° 3'18.48"E	Plot No. 137/H, I-9, Industrial Area, Islamabad			

49.	C-23961	Marble Processing	Citi Marble Industries		33°39'51.70" N	73° 3'20.88"E	Plot No.277,Street No.1 , I-9, Industrial Area, Islamabad				
50.	C-23961	Marble Processing	Arit Marbles chips and powder Factory		33°39'32.58" N	73° 2'24.25"E	Plot No. 357, Street No.5, I-9/3, Islamabad				
51.	C-23961	Marble Processing	Hassan Marbles		33°39'26.11" N	73° 3'22.83"E	Plot No. 375 H, I-9, Potohar Road,Industrial Area, Islamabad				
52.	C-23961	Marble Processing	Unique Marbles		33°39'27.48" N	73° 3'16.05"E	Plot No. 253 B, Street No.6, I-9/3, Islamabad				
53.	C-23961	Marble Processing	Crescent Marbles Granites		33°39'52.52" N	73° 3'16.41"E	I-9/3, Industrial Area, Islamabad				
54.	C-23961	Marble Processing	Mughal Marbles and Granites		33°39'23.27" N	73° 3'15.70"E	Plot No. 137 F,I-9, Industrial Area, Islamabad				
55.	C-23961	Marble Processing	International Granite Marbles		33°39'22.84" N	73° 3'14.81"E	Plot No. 137 E, I-9 Industrial Area, Islamabad				
56.	C-23961	Marble Processing	Atlas Marble Industries		33°39'22.17" N	73° 3'14.56"E	Plot No. 137 E, I-9 Industrial Area, Islamabad				
57.	C-23961	Marble Processing	National Marles and Granite		33°39'21.76" N	73° 3'13.68"E	Plot No. 137 D, I-9 Industrial Area, Islamabad				
58.	C-23961	Marble Processing	Saeed Marbles		33°39'21.28" N	73° 3'12.90"E	Plot No. 137 C, I-9 Industrial Area, Islamabad				
59.	C-23961	Marble Processing	Daniyal Marbles		33°39'23.99" N	73° 3'14.42"E	Plot No. 137 F, I-9 Industrial Area, Islamabad				

60.	C-23961	Marble Processing	Kashmir Marble Factory		33°39'23.11" N	73° 3'17.12"E	Plot No. 137 G, I-9 Industrial Area, Islamabad			
61.	C-23961	Marble Processing	Star Marbles Industries		33°39'38.12" N	73° 2'45.72"E	Plot No. 215 Street No 07, I-9/2 Industrial Area, Islamabad			
62.	C-23961	Marble Processing	Orient Marbles		33°39'31.03" N	73° 2'55.64"E	Plot No. 84,St.10, I-9/2 Industrial Area, Islamabad			
63.	C-23961	Marble Processing	K-2 Marble Industries				Plot no. 126-Astreet No 15, I-9/2, Islamabad			
64.	C-23961	Marble Processing	Irum Marble Industries		33°39'24.79" N	73° 3'9.22"E	Plot No. 114, Street No. 15, I-9 Industrial Area, Islamabad			
65.	C-23961	Marble Processing	Naseem Marble Industry		33°38'58.03" N	73° 2'16.12"E	Plot No. 163,I-10/3, Industrial Area, Islamabad			
66.	C-23961	Marble Processing	New Bagh Marble Industry				Plot no. 42-B, Street No. 11, I-(/2, Islamabad			
67.	C-23961	Marble Processing	Amish Marble				Plot no. 57, Street No13, I-9/2 Islamabad			
68.	C-23961	marble processing	Kohsar Industries		33°39'51.61" N	73° 3'16.51"E	Plot No. 204,205,220, Street No. 10, I-9 Industrial Area, Islamabad			
69.	C-2100	Pharmaceutical	Wilson's Pharmaceuticals	Mr. Ali Amin	33°39'33.14" N	73° 3'36.82"E	Plot no. 387-388, I-9, Sector, Industrial Area, Islamabad	werrick.pharma@gmail.com		

70.	C-2100	Pharmaceutical	Benson Pharmaceuticals	Mr. Javed Iqbal Satti	33°39'4.14"N	73° 2'16.12"E	Plot NO. 119, Street No. 8, I-10/3, Industrial Area Islamabad	javidsatti@hotmail.com		
71.	C-2100	Pharmaceutical	Werrick Paharmaceuticals	Mr. Ali Amin Sheikh	33°39'17.24"N	73° 2'38.47"E	Plot No. 216-217, I-10/3, Industrial Area, Islamabad	werrick1@dsl.net.pk		
72.	C-2100	Pharmaceutical	Werrick Health Care		33°38'59.47"N	73° 2'19.01"E	Plot No. 161, Street No. 9, I-10/3, Industrial Area, Islamabad			
73.	C-2100	Pharmaceutical	Attabak Pharmaceuticical		33°39'21.61"N	73° 2'35.89"E	Plot No. 5 C, I-10/3, Industrial Area, Islamabad			
74.	C-2100	Pharmaceutical Products	Leads Pharma	Dr. Muhammad Amjad	33°39'11.62"N	73° 2'2.22"E	Plot no. 81-A, Street No. 6, I-10/3, Islamabad	info@vetycare.com	http://www.vetycare.com.pk/	
75.	C-2100	Pharmaceutical Products	Maksons Pharmaceuticals	Mr. Kifayat H. Malick	33°39'14.74"N	73° 2'7.32"E	Plot No. 80-B, Street No. 6, I-10/3, Industrial Area Islamabad	kifayat_makson@hotmail.com		
76.	C-2100	Pharmaceutical Products	Pearl Pharmaceuticals	Mr. M. Humayun Latif	33°39'4.91"N	73° 2'40.64"E	Plot No. 204, Street No.1, I-10/3, Industrial Area, Islamabad	info@pearl.com.pk	http://www.pearl.com.pk/	ISO 9001:2008
77.	C-2100	Pharmaceutical Products & machinery	Scotmann Pharmaceuticals	Mr. Ali Ameen	33°39'19.78"N	73° 2'37.56"E	Plot No. 5-D, I-10/3, Industrial Area, Islamabad	wwp@scotmann.com.pk	http://www.scotmann.com/index.html	
78.	C-24108	Steel pipes	Sachal pipes and pipe fittings		33°39'21.24"N	73° 2'10.63"E	Plot No. 60 D, Street No. 7, I-10/3, Industrial Area, Islamabad			

79.	C2100	Flour Processing	Rehmania Flour Mills	Mr. Ahmed Menai	33°39'53.86" N	73° 3'9.20"E	Plot No. 157, I-9, Industrial Area, Islamabad			
80.	C-22202	PVC Coated Wires	Dawn Electric Industries	Mr. Maqsood Afzal	33°39'31.34" N	73° 3'28.55"E	Plot No. 382-383, Sector I-9/3, Islamabad			
81.	C-22202	PVC Pipes	Pakistan PVC Ltd.	Mr. Adeel Shaffi	33°39'35.96" N	73° 2'37.22"E	Plot No. 1-4, & 31-A, I-9, Industrial Area, Islamabad	adeelshaffi@shavyl.com	http://www.shavyl.com/	
82.	C-22202	PVC Pipes	TF Pipes Ltd.	Mr. Khawar Nawaz	33°39'42.06" N	73° 2'57.03"E	Plot No. 159-163, Street No.2, I-9/2, Industrial Area, Islamabad	adeelshadeelshaffi@shavyl.com	http://www.tfpipes.com/	
83.	C-22202	PVC Pipes	Akbar & Zikria Pipes Pvt. Ltd	Mr. Muhammad Zikria A Zia	33°39'50.12" N	73° 3'15.60"E	Plot No. 202, 203, Street No. 2, I-9/3, Industrial Area, Islamabad	zikriazia@yahoo.com		
84.	C-22202	PVC Pipes	Master Plus		33.6863232,	73.0292224	I-9/2 Islamabad, Islamabad Capital Territory	-		
85.	C-24104	Structural Steel products	Taibah Steel Re-Rolling Mills		33°39' 51.70"N	73° 3'42.01"E	Plot No. 412, I-9, Industrial Area, Islamabad			
86.	C106b	Rice Polishing and finishing	Barkat Rice Mills		33°39'13.03" N	73° 2'34.21"E	Plot No. 220-223, Street No. 1, I-10/3, Industrial Area, Islamabad			
87.	C20232	Soap Manufacturing	Islamabad Soap & Chemical Industries	Sh. Muhammad Muneer	33°39'38.12" N	73° 3'14.89"E	Plot No. 240, I-9, Sector, Industria Area, Islamabad	-		
88.	C20232	Soap Manufacturing	Rose Enterprises Chemical Industr	Mr. Imran Aftab	33°39'50.40" N	73° 3'14.59"E	Plot No. 201, Street No. 2, I-9/3 Industrial Area Islamabad	imranaftab@hotmail.com		

89.	C20232	Soap Manufacturing	Mujahid Soap & Chemical Industries Pvt. Ltd	Sh. Muhammad Suleman	33°39'33.22" N	73° 2'50.07"E	Plot no. 79-80, Street No. 10, I-9, Industrial Area, Islamabad				
90.	C20232	Soap Manufacturing	Sethi Soap Industries	Mr. Iftikhar Anwar Sethi	33°39'25.9"N	73° 3'00.5"E	Plot No. 97, Street No. 14, I-9, Industrial Area, Islamabad	muhammadusman.sethi@yahoo.com			
91.	C20232	Soap Manufacturing	New karachi Soap Industries		33°39'38.44" N	73° 3'8.07"E	Plot No. 225, I-9 Industrial Area, Islamabad				
92.	C-13921	Spinning of woolen yarn, carpet yarn	Sarhad Woolen Mills (Pvt) Ltd.	Syed Mansoori Jan	33°39'38.39" N	73° 3'15.17"E	Plot No. 242,Street No. 8, I-9, Industrial Area Islamabad	mjan@multisoftpk.com			
93.	C-24104	Steel Furnace	Pak Iron & Steel Pvt Ltd	Mr. Rafat Farid	33°39'17.13" N	73° 2'49.17"E	Plot NO. 24, I-9 Sector, Industrial Area Islamabad	rafat.farid@pakiron.pk			
94.	C-24106	Structural Steel products	Pak Iron & Steel Pvt Ltd	Mr. Rafat Farid	33°39'17.13" N	73° 2'49.17"E	Plot NO. 24, I-9 Sector, Industrial Area Islamabad	rafat.farid@pakiron.pk			
95.	C-24106	Structural Steel Products	M. Muhammad Hussain & Sons Pvt. Ltd.	Mr. Zahid Iqbal	33°39'2.07"N	73° 3'36.32"E	Plot No. 191-192, I-10/3, Industrial Area, Islamabad	masteel@apollo.net.pk			
96.	C-24106	Structural Steel products	Islamabad Steel Re-rolling Mills	Mr. Muhammad Asif Paracha	33°39'31.03" N	73° 2'51.80"E	Plot No.54, Street no. 10, I-9/2, Industrial area, Islamabad				
97.	C-24104	Steel Furnace	Karachi Steel & Re-rolling Mills	Mr. Umar Hussain	33°39'1.45"N	73° 2'35.22"E	Plot No. 191, I-10/3, Industrial Area, Islamabad	info@karachisteel.com			
98.	C-24106	Structural Steel products	Karachi Steel & Re-rolling Mills	Mr. Umar Hussain	33°39'1.45"N	73° 2'35.22"E	Plot No. 191, I-10/3, Industrial Area, Islamabad	info@karachisteel.com			

99.	C-24106	Structural Steel products	Zia Steel Re-rolling Mills	Mr. Ammad Naveed	33°39'24.86" N	73° 2'21.87"E	Plot No. 48, Street No. 2, I-10/3, Islamabad	ziasteel@hotmail.com		
100.	C-24106	Structural Steel products	Capital Steel Industries	Mr. Muhammad Rafique Minhas	33°39'41.58" N	73° 3'12.63"E	Plot No. 229-230, Street No. 7, I-9, Industrial Area, Islamabad	capital.steel001@gmail.com		
101.	C-24106	Structural Steel products	New Classic Steel Re-rolling Mills	Mr. Iftikhar Ahmed Abbassi	33°39'21.65" N	73° 3'5.13"E	Plot No. 102, Street No.15, I-9, Industrial Area, Islamabad	csrmpk@gmail.com	SGI Group	
102.	C-25112	Steel and aluminim fabrication Works	Solajan		33°39'13.08" N	73° 2'3.77"E	Plot No. 79, Street No. 6, I-10/3, Industrial Area, Islamabad			
103.	C-24106	Structural Steel products	M.I.Z Re-rolling Steel Mills	Malik Mussarat Hussain	33°39'32.87" N	73° 3'11.68"E	Plot nO. 248, I-9/2, Industrial Area, Islamabad	mizsteel@hotmail.com		
104.	C-24104	Steel Furnace	Ittehad Steel Industries	Mr. Khalid Javed	33°39'46.52" N	73° 3'45.38"E	Plot No. 417, I-9, Industrial Area, Islamabad	info@ittehad.com.pk		
105.	C-24106	Structural Steel products	Ittehad Steel Industries	Mr. Khalid Javed	33°39'46.52" N	73° 3'45.38"E	Plot No. 417, I-9, Industrial Area, Islamabad	info@ittehad.com.pk		
106.	C-24106	Structural Steel products	H.S Steel Re-rolling Mills	Mr. Akhtar Hafeez	33°39'31.28" N	73° 2'48.05"E	Plot NO. 50-55, Street No. 12, I-9/2, Industrial Area Islamabad	akhtarhafeez@hotmail.com		
107.	C-24106	Structural Steel products	Siddque Steel & Re-rolling Mills	Mr. Sohail Siddique	33°39'24.01" N	73° 2'57.52"E	I-9 Industrial Area, Islamabad		SGI Group	
108.	C-24106	Structural Steel products	Hassan Steel Re-Rolling mills		33°39'36.75" N	73° 2'46.06"E	Plot No. 37,38,39,Street No10 I-9 /2Industrial Area, Islamabad			

109.	C-24106	Structural Steel products	R.K. Steel	Mr. Muhammad Multazim Raza Khan	33°39'27.37" N	73° 2'47.50"E	Plot NO. 50A, I-9, Industrial Area Islamabad	nasirkhan@rksteel.com.pk		
110.	C-24104	Steel Furnace	Fazal steel Pvt .Limited		33°39'24.40" N	73° 2'42.18"E	Plot No. 13,14, I-9/2, Industrial Area, Islamabad			
111.	C-24106	Structural Steel products	Fazal steel Pvt .Limited		33°39'24.40" N	73° 2'42.18"E	Plot No. 13,14, I-9/2, Industrial Area, Islamabad			
112.	C-24106	Structural Steel products	J.R. Steel Re-rolling Mills	Mr. Muhammad Imran	33°39'25.93" N	73° 2'15.87"E	Plot No. 57, I-10/3, Industrial Area, Islamabad	jr_steel57@yahoo.com		
113.	C-24106	Structural Steel products	Nomee Industries Steel Re-rolling Mills.	Mr. Muhammad Dawood Khan	33°39'23.81" N	73° 2'54.86"E	Plot nO. 431, Stree No. 14, I-9/2, Industrial Area Islamabad	mdk@nomeesteel.com		
114.	C1079	Tomato Ketchup	Kanas Pvt. Ltd.	Mr. Usman Khalil Noon	33°39'17.90" N	73° 2'13.30"E	Plot No. 60, Street No. 7, I-10/3, Industrial Area, Islamabad	usman.khalil@live.com		
115.	C-20236	Cosmetics and toiletries	Cosmo pro Pvt.Limited		33°39'1.41"N	73° 2'22.06"E	Plot No. 145, Street No. 9, I-10/3, Industrial Area, Islamabad			
116.	C-25112	Fabircated Metal Products	Sirius Driling Gemstone	Mr. Muhammad Haseeb	33°39'4.56"N	73° 2'27.84"E	Plot No. 150, Street No. 9, I-10/3, Industrial Area, Islamabad			
117.	C-13921	Wool caps	SB Traders		33°39'4.58"N	73° 2'27.84"E	Plot No. 118 Street No. 8, I-10/3, Industrial Area, Islamabad			

118.	C-31001	Sofa, beds, Chairs	Noor Timber Trading Co		33°39'4.37"N	73° 2'14.05"E	115, Street No. 8, I-10/3, Industrial Area, Islamabad			

APPENDIX-VIII

PUBLICATION

The output of synthesis of review of literature has been published in following article in *Applied Ecology and Environmental Research* **17**(1):1159-1221 (2019)

titled

"*A BIBLIOMETRIC ANALYSIS OF CONTEMPORARY RESEARCH REGARDING INDUSTRIAL SYMBIOSIS: A PATH TOWARDS URBAN ENVIRONMENTAL RESILIENCE*"

Akhtar et al.: A bibliometric analysis of contemporary research regarding industrial symbiosis: A path towards urban environmental resilience
- 1159 -

A BIBLIOMETRIC ANALYSIS OF CONTEMPORARY RESEARCH REGARDING INDUSTRIAL SYMBIOSIS: A PATH TOWARDS URBAN ENVIRONMENTAL RESILIENCE

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Abstract. The conceptual framework of industrial symbiosis (IS) is gaining recognition for ensuring the conservation of natural resources and resilience of socio-ecological surroundings. Significant scholastic strides have been made for explaining the conceptual paradigm of IS. The current study relied upon the Bibliometric mapping technique to decipher the contemporary orientations in the recent publications (2007-2017). The findings revealed that China, UK and the USA are the pivot for promoting research interests in the field. The loci of IS research was observed more skewed in favour of economically developed and industrialized countries. The findings of this study also acknowledge a growing propensity towards research collaboration between and among nations.
Keywords: *industrial ecology, bibliometric analysis, ecological sustainability, environmental resilience, applied ecology*

Introduction

Industrial symbiosis (IS) initially emerged as a branch of the industrial ecology (IE). Laybourn and Lombardi (2012) opined that the theoretical framework of IS is based on engaging diverse production activities, through an integrated network to foster eco-innovation and long term cultural changes. This emerging branch of knowledge tries to elaborate the interconnectedness of natural environment and human society (Chertow, 2008). Therefore, an understanding regarding mutualistic relationships among organism help to re-design the process of industrial production for the sustainability of natural resources (Desrochers, 2001; Zhang et al., 2015a). The conceptual framework is gaining acceptance as a pragmatic strategy to improve efficiency in production activities (Laybourn and Lombardi, 2012). These strategies are obligatory and incumbent for ensuring the conservation of natural resources and achieving the goals of social, economic and environmental sustainability.

The paradigm of IS envisaged a framework to engage traditionally disparate industrial activities in a synchronized manner for maximizing advantages. Thus, it emphasizes on physical exchange of materials, energy, water and byproducts through integrated linkages (Chertow, 2000). The traditional modus operandi in this regard was through collaboration and exploring the synergistic possibilities that transpire through

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preconceived integrations in a limited geographic proximity. However, with the advancements in theory and practice, the scope of IS now transcends the limitations of physical proximity (Laybourn and Lombardi, 2012).

Significant scholastic efforts have been made for explaining the concept of IS, defining its boundaries, its evolution, progression, practices and different strategies adopted to implement it during the last two decades (Chertow, 2000; Mirata and Pearce, 2006; Baas, 2011; Martin and Eklund, 2011; Laybourn and Lombardi, 2012; Lombardi et al., 2012; Maclachlan, 2013; Marinos-Kouris and Mourtsiadis, 2013; Alfaro and Miller, 2014; Chertow and Park, 2016; Mauthoor, 2017). During this period, the focus of IS research witnessed a number of evolutionary transformations. Chertow and Park (2016) substantiated that the conceptual frameworks of inquiry in IS are changing in response to socio-economic and technological changes. They also perceived that such propensities are quite evident in case studies, mechanism adopted for investigations, proposals designed for investigations and modelling techniques relied upon for analysis in IS studies. In this connection, Paquin and Howard-Grenville (2013) pronounced another aspect of such evolutionary tendencies and termed it a shift from “blind dates” to “arranged marriages”. Elaborating on this, they maintained that many of contemporary developments in the domain of IS research are now being facilitated by either governmental or non-governmental factors. The growing research inclinations in China towards IS are often cited to corroborate such assertions. In this country, the availability of large networks of eco-industrial parks (EIP) facilitated by the China National Demonstration Eco-Industrial Park Program are encouraging scientific publications in the field of IS. The other notable initiatives of similar objectives are National Industrial Symbiosis Program in the United Kingdom (UK) and Resource Efficiency Flagship Initiative in Europe (Laybourn and Lombardi, 2012; Paquin and Howard-Grenville, 2013).

Despite increasing importance and interest in IS, focus on recalling earlier advances in the domain appeared a less explored arena of research. Two important review papers authored by Yu et al. (2014) and Chertow and Park (2016) attempted to comprehensively review the orientations of research in this domain. The former researcher tried to quantitatively map and mention the noticeable strides in this domain from 1997 to 2012, while, the latter focused on the time period from 1997 to 2014. These researchers not only identified the seminal articles but also identified key themes, researchers and journals in this branch of knowledge. These researchers concluded that the field of IS stemmed from and was rooted in IE. Yu et al. (2014) identified five distinctive topical areas in the contemporary IS research i.e. wastewater treatment and management, solid waste management, energy efficiency, self-organization of IS systems, and policy making and evaluation of IS and EIP projects. Whereas, Chertow and Park (2016) sub-divided their assertions into seven categories based on the nature of study: Foundation, Performance, Mechanism, Modeling, Structure, Case Study, and Proposal.

However, both of these studies deployed bibliometric analysis technique for assessments. The Bibliometric or Scientometric mapping (Cobo et al., 2011) approach is a visual technique of informatics. This assessment approach quantitatively displays structural and dynamic aspects of scientific research proclivities for the specified temporal duration (Liu and Gui, 2016). The technique also offers replicable opportunities for quantitative estimations and visual mapping in the domain of ecology (Neff and Corley, 2009; Govindaradjou and John, 2014). These features enable to

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understand the noticeable progressions in the field of interest for systematic review and assessments. It empowers the researchers to decipher the impacts of inter-disciplinary imprints on the prevailing mode of investigations.The bibliometric analysis is also considered helpful for postulating about the emerging trajectories in research orientations (Yu et al., 2014). The similar nature of methodologies have been relied upon for analyzing evolutionary developments and contemporary advances in diversified fields of knowledge (Eito-Brun and Rodríguez, 2016; Liu and Gui, 2016; Mishra et al., 2016; Atif et al., 2018).

The current research was designed to assess the contemporary trends regarding IS research by evaluating the recent publications (2012-2017). The study was designed to identify the salient features of the recent research concerning IS. Besides identifying research inclinations, the study will also attempt to provide a snapshot of key research networks and subject areas of recent publications. Thus, the present study will provide an opportunity to synchronize the efforts for environmental sustainability in the present phase of rapid population growth, urbanization and looming industrialization in the developing world.

Material and methods

The Bibliometric or Scientometric mapping technique was relied upon to decipher the contemporary research orientations in the domain of IS. This study deployed co-occurrence analysis technique to identify networks of collaborating organizations, countries, citations and co-authorships. The technique facilitates the representation of the related items with the help of networks maps through nodes and links (Liu and Gui, 2016). The size of the node is a measure of centrality and thus depicts the importance of the impacts (Wasserman and Faust, 1994). The larger nodes served as hubs in the analysis thereby depicting the significance of articles, keywords, and authors.

The technique is considered reliable (Yu et al., 2014) and was deployed to analyse the spatio-temporal trends and to identify intellectual communities engaged with research concerning IS. It was subsequently relied upon for the "keyword co-occurrence analysis test" to understand the emerging developments in the domain of IS studies. *Table 1* succinctly describes the nature and scope of study, data sources and the methodology implemented for data retrieval and assessments of facts.

Data collection and preparation

The current study is a meta-analysis, based upon the bibliographic information, retrieved from Scopus. The study focused on the research published between January 2012 till March 2017 against the search term "industrial symbiosis". Ostensibly, it seems that the use of a single keyword may compromise the authenticity of findings by excluding the related studies with different nomenclatures but at the same time avoiding digressions. The study carried out by Atif et al. (2018) has successfully experimented this technique. The query returned 398 records, which were further scrutinized for relevance. On this criteria, a total of 395 records (*Appendix-I*) were selected for further processing. The data was refined using Notepad ++ to standardize the variants used in keywords, authors, journals, organizations and country names.

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Table 1. Study approach adopted for exploring research productivity trends in IS (2012-17)

Objectives	Questions	Indicators
Spatio-temporal distribution of IS research productivity	How many documents are published annually?	Number of documents published per year
	Which are the most productive countries?	Number of publications per country
	Key institutions involved in IS research	Ranking of key organizations and collaboration network
Identify most productive research communities	Who are the most productive authors?	Ranking of most productive authors by complete count method
	Who are the authors that collaborate?	Co-authorship Analysis
	Who are authors that share a common interest?	Co-citation analysis
Key lines of research	Which are the key subject areas under which IS research is being carried out?	Contribution by subject based on Scopus classification
	What are the key themes of IS research?	Keyword Co-occurrences

Data Analysis

The data for current study was analyzed with the help of Bibexcel (Persson et al., 2009) and bibliographic networks developed in VOS Viewer (Van Eck and Waltman, 2011). Bibexcel was used due to its flexibility, ability to handle a large amount of data and its compatibility with other softwares like Excel, Pajek and VOS Viewer (Mishra et al., 2016). The network data obtained from Bibexcel was further processed in VOS Viewer to develop network maps. The findings were subsequently relied upon for depicting salient characteristics of the selected studies. The bibliometric indicators like annually published articles, country wise publication, top authors, top journals and subject categories were directly obtained from Scopus. The content analysis of the selected publications was carried out to scrutinise the causations responsible for reported orientations in contemporary research regarding IS.

Results

Since the study aims, primarily, to cover all aspects of research concerning IS for the time period from 2012 to 2017, therefore all documents, from all countries and languages available have been thoroughly scrutinized. For this purpose 395 publications, specifically related to "industrial symbiosis" were retrieved from the Scopus database for the selected time interval. These studies were carried out by the authors from 24 countries related with 20 different disciplinary areas. The data retrieved included: articles (262), other documents included conference papers (59), book chapters (28), articles in press (22), review articles (15), conference reviews (4), books (2), editorials (2) and the solitary available note. These articles were published in three languages: English (383), Chinese (10) and German (2).

In this connection, the following top five journals were observed in the forefront i.e. Journal of Cleaner Production (92), Journal of Industrial Ecology (JIE) (43), Resources, Conservation and Recycling (13), Computer Aided Chemical Engineering (11) and Shentai Xuebo Acta Ecologica Sinica (11). These five journals account for 42.7% of the total published documents.

Spatio-temporal distribution of research

The spatio-temporal connotations of these scholastic linkages were also magnified with the help of distribution maps and statistical diagrams. The approach is considered helpful for depicting the scholastic collaborations between and among nations (Liu and Gui, 2016). The topic of IS appeared in literature around 1997, afterward, it grew exponentially with correlation coefficient $r^2 = 0.88$ (*Figure 1*). The findings in *Figure 1* also depicting the research productivity of the previous five years (2012-17) in relation to overall research published since 1997.

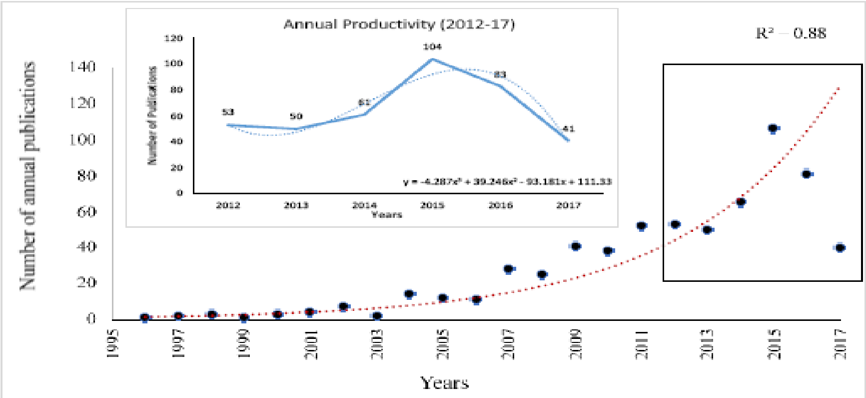

Figure 1. *Annual productivity in IS research (1997-2017), while recent fluctuations encompassing the time period (2012-17) have been condensed in the inset*

Spatial scope of IS has expanded to 24 countries (*Figure 2*) during this period and research hubs are mainly located in industrialized contextual settings (*Appendix-II*) such as China (85), United Kingdom (49) and United States (49). The other countries with significant contributions are Italy (34), Japan (27), Netherlands (21), Philipines (21), Australia (19), Canada (19), and France (19). The findings revealed that about 363 organizations from these countries are involved in IS research. In this connection De-La-Salle University, Manila (22), National Institute for Environmental Studies for Japan (21), University of Surrey, United Kingdom (19), University of Tokyo, Japan (11), Tsinghua University, China (11) and the University of Nottingham, Malaysia (11) are the most prominent contributors towards IS research.

The subsequent co-occurrence frequency analysis depicted a growing tendency towards collaboration between and among different nations. In this regard, the highest scientific collaboration was observed between China and Japan in (17) cases. The participating organizations in these collaborations are the Chinese Academy of Sciences, the National Institute of Environmental Studies (NIES), Japan and Nagoya University, Japan. The researchers such as Liang Dong, Tsuyoshi Fujita affliated with NIES, Japan and Yong Geng, chief researcher in Chinese Academy of Sciences are, apparently, the most active contributors in this collaboration network. Most of these scientific research collaborations in this network were funded through various programs of Natural Science Foundation of China (11) and Ministry of Environment, Japan (8).

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 17(1):1159-1221.
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Research Communities

The current study also attempted to identify the most productive authors with respect to a number of publications during the similar time period (2012-2017). The ranking is based on the complete count method. In this scheme of assessments every occurrence of the author is counted provided his name has been mentioned in the list of co-authors in a publication selected for this study. Total citations and h-index were subsequently calculated using the Bibexcel and presented in *Figure 3*.

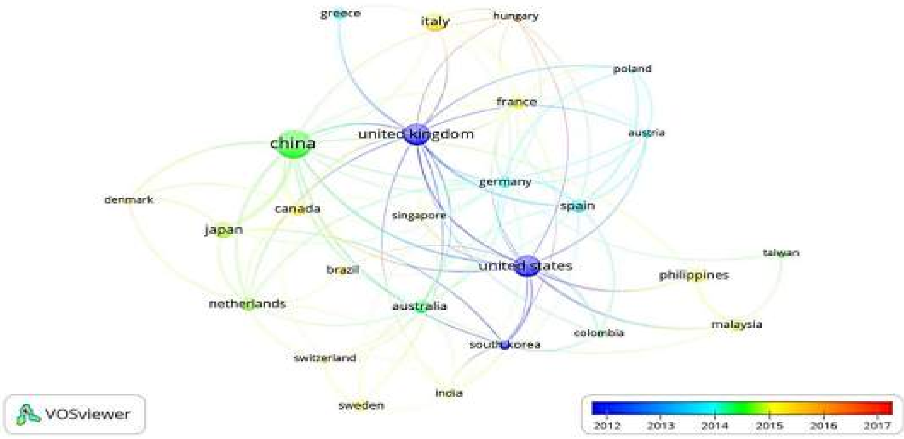

***Figure 2.** Geographical network of IS research productivity retrieved from corresponding author addresses (2012-17)*

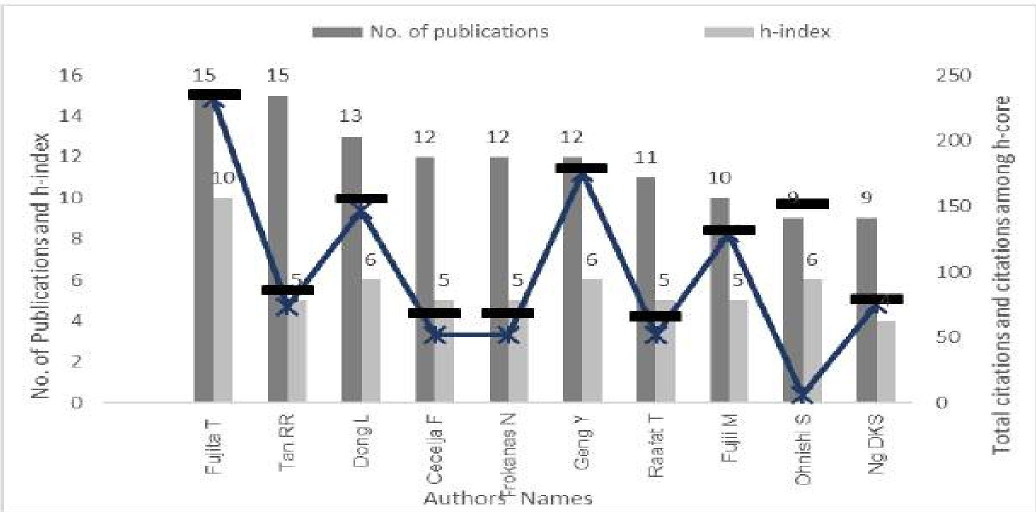

***Figure 3.** Ten most productive authors based on number of publications and h-index (N=395)*

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 17(1):1159-1221.
http://www.aloki.hu • ISSN 1589 1623 (Print) • ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1701_11591221

Tsuyoshi Fujita from NIES, Japan and Raymond R. Tan from De La Salle University Philippines were observed as the two most proficient and productive authors with 15 publications apiece. It is pertinent to mention that NIES, Japan (20) and De La Salle University (33) also emerged as the most productive organizations. However, scientific contributions by Tsuyoshi Fujita has received more acknowledgments in terms of citations (235), than Raymond R. Tan (86).

Clusters in research collaborations

The selected publications were analyzed to find out the scale and orientation of contemporary research collaborations. To identify the most productive collaborating authors, a co-authorship network map was developed using VOS viewer (*Figure 4*). The findings have been condensed in *Table 2*. The findings in the table explicitly convey the affiliations of authors, the focus of research and published studies ensuing from these research collaborations.

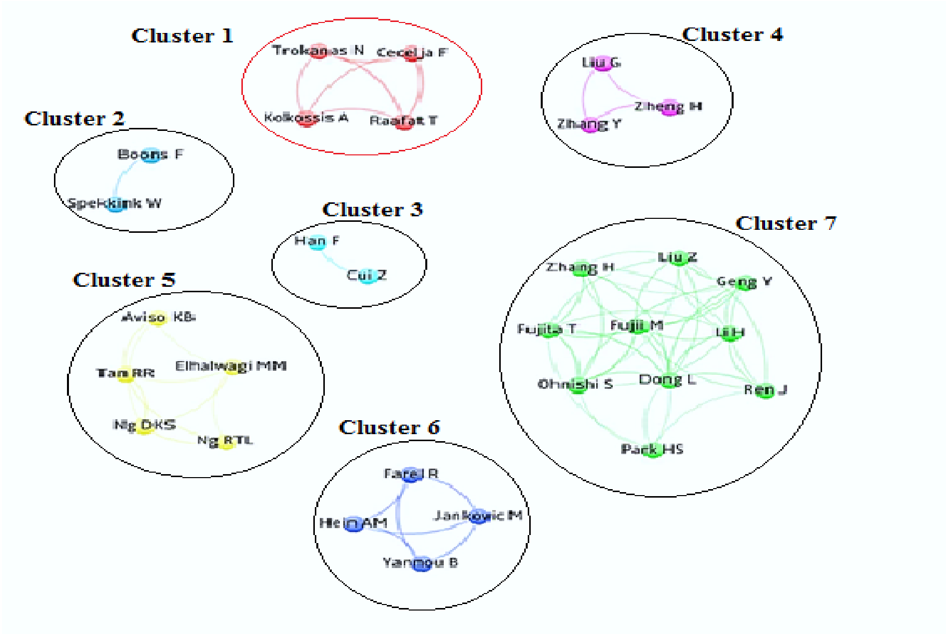

Figure 4. Co-authorship network with seven clusters working on IS

Co-citation analysis

Co-citation analysis technique is also relied upon to understand the conceptual orientations and imprints of contemporary research. The findings of current study in (*Figure 5*) portrayed that Marian Chertow, Yong Geng and Raymond Tan have the significant bearings and followings in the domain of IS research.

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 17(1):1159-1221.
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Table 2. Co-authorship cluster classification with affiliations and research areas

Cluster Number	Scholars Affiliation	Research Area	Reference Literature
Cluster 1	Center for Process and Information Science, Faculty of Engineering and Physical Science, University of Surrey, UK National Technical University, Athens, Greece	Semantic and ontological approaches for IS	(Trokanas et al., 2012; Trokanas et al., 2014b; Trokanas et al., 2014a; Trokanas et al., 2014c; Trokanas et al., 2015a; Trokanas et al., 2015b)
Cluster 2	Sustainable Consumption Institute, University of Manchester, UK University de los Andes, Bogota, Columbia	IS dynamics and influence of different factors	(Boons et al., 2011; Boons and Spekkink, 2012; Boons et al., 2014; Boons et al., 2015; Boons et al., 2017)
Cluster 3	School of Environmental Science and Engineering, Shandong University, China	IS application in China	(Yu et al., 2015b; Yu et al., 2015c; Yu et al., 2015a)
Cluster 4	State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, China	Network analysis of IS Systems	(Zhang et al., 2013a; Zhang et al., 2013b; Zhang et al., 2013c; Zhang et al., 2015a; Zhang et al., 2015b; Zhang et al., 2015c; Zhang et al., 2016)
Cluster 5	Center for Engineering andSustainable Development Research, De La Salle University, Manila, Philippines Department of Chemical and Environmental Engineering, Centre of Excellence for Green Technologies, University of Nottingham, Malaysia Campus. Department of Chemical and Biological Engineering, University of Wisconsin, United States	Fuzzy programming and optimization based IS system and EIP designs	(Ng et al., 2014a; Ng et al., 2014b; Ng et al., 2014c; Tan et al., 2016)
Cluster 6	Laboratoire Genie Industriel, CentraleSupélec, Université Paris-Saclay, France, Paris-Saclay Energy Efficiency (PS2E), France	EIP design architecture and modelling for IS	(Hein et al., 2015a; Hein et al., 2015b; Hein et al., 2016; Hein et al., 2017a; Hein et al., 2017b)
Cluster 7	National Institute for Environmental Studies, Japan National Engineering Laboratory for Hydrometallurgical Cleaner Production Technology, Institute of Process Engineering, Chinese Academy of Sciences, China. Center for Social and Environmental Systems Research, National Institute for Environmental Studies (NIES), Japan Centre for Engineering Operations Management, Department of Technology and Innovation, University of Southern Denmark. School of Environmental Science and Engineering, Shanghai Jiao Tong University, China University of Ulsan, South Korea	Low carbon IS options, environmental and economic benefits of IS for China	(Geng et al., 2009; Dong et al., 2013; Zhang et al., 2013a; Zhang et al., 2013b; Zhang et al., 2013c; Zhang et al., 2015a; Zhang et al., 2015b; Zhang et al., 2015c; Zhang et al., 2016)

Keyword analysis

Keyword co-occurrence maps represent the cognitive structure of a discipline. Atif et al. (2018) opined that the selection of keywords depicts the focus and orientation of the scientific research. For this purpose, the keywords from the publications were retrieved

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 17(1):1159-1221.
http://www.aloki.hu • ISSN 1589 1623 (Print) • ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1701_11591221

Akhtar et al.: A bibliometric analysis of contemporary research regarding industrial symbiosis: A path towards urban environmental resilience
- 1167 -

and processed for analysis. The findings have been illustrated in *Figure 6*. Only such terms as the ones recurring at least five times were mentioned. The strategy was deployed to overcome the excessive noise. *Figure 6* displays an overlay visualization of the keyword co-occurrences. The size of the node reflects frequency, while, the color of the node represents the publishing time period.

The central nodes represent the keywords such as "industrial symbiosis" (277), "industrial ecology" (123), "sustainable development" (77), "industry" (76), and "eco-industrial park" (67). Whereas, the keywords like "waste management" (43), "environmental impacts" (42) "recycling" (41), "economics" (39), "Life cycle assessment" (33) and "carbon" (25) also appeared significantly in the analysis (*Figure 6*).

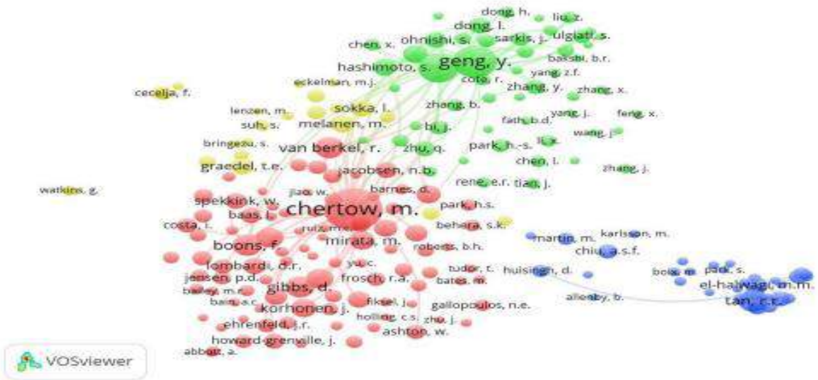

Figure 5. *Co-citation network map of cited authors in documents retrieved from Scopus database*

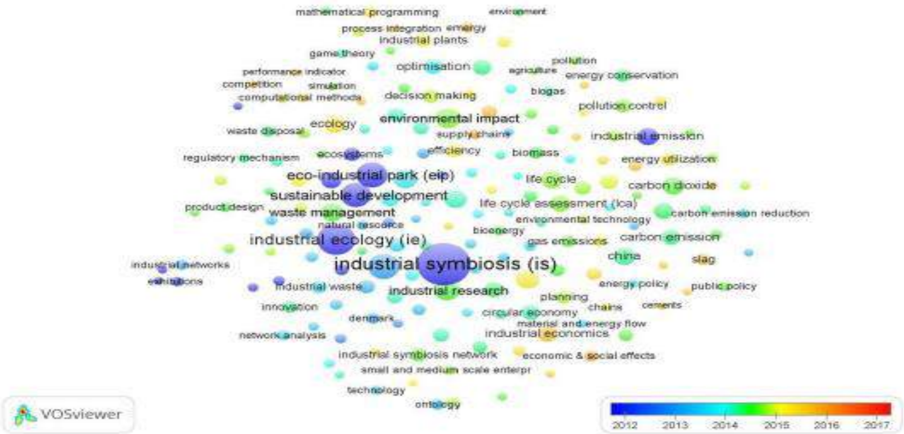

Figure 6. *Keyword occurrences in IS related literature for the period 2012-17*

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 17(1):1159-1221.
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Discussion

The resource depletion, accelerating demands for goods and services are compelling the human conscience to strive for environmental and ecological sustainability. The researchers and policy makers are striving to postulate doable measures to achieve these goals. Chertow (2000) proclaimed that in response to these demands the research inclinations towards IS started to gain acceptability from 1997 onwards. The findings of the study in *Figure 1* corroborate and substantiate these assertions. During the span of two decades (1997-2017), IS has evolved from a “signature topic” (Lifset, 2012) in IE to a more systematic, promising and advancing research discipline. As a result, the IS studies are gaining significant attention.

The findings of the study revealed that a large share (34%) of the publications were contributed by two journals, namely Journal of Cleaner Production and Journal of Industrial Ecology (JIE); similar findings were reported by Yu et al. (2014).

The findings in the *Figure 2* also pointed towards growing research collaboration between and among nations, ranging from regional to inter-continental engagements. These findings are in line with the assertions of previous investigations. In this connection, Chertow and Park (2016) and Yu et al. (2014) opined that IS is as advancing interdisciplinary field and rapidly attracting the attention of the research community. In this regard, China from Asia, UK from Europe and USA from the North America were identified as the hub and stimulator for promoting research interests in the field. Whereas, the findings of this study also portrayed that the majority of collaborations are being carried out by developed industrial economies. While the orintation towards IS research was observed in fomenting stages in the southern hemisphere. However, a growing penchant for such cross-country collaborations was also noticed, such as India (7) which is shifting from an agricultural to an industrial economic base.

The research collaborations are needed and encouraged (Iglič et al., 2017) for postulating pragmatic strategies to address the issues from divergent contextual settings. The findings based upon co-authorship analysis help to identify major research groups/collaborations in the field of IS. The findings in *Figure 1* and *Table 2* portrayed the emergence of seven distinctive streams of investigations as an outcome of these research collaborations. The most frequent research collaborations were observed among the researchers from China, Japan, Phillipines and UK. The most productive cluster (07) published (09) papers. This collaboration was observed among researcher from NIES, Japan, Chinese Academy of Sciences, China, University of Southern Denmark and University of Ulsan South Korea. This cluster is also the biggest in terms of number of researchers (10) engaged in collaboration.

The findings of the study (*Figure 5*) substantiate the previous assertions of Yu et al. (2014) that the scholastic contributions of Marian Chertow have more acknowledgment than any other scholar in the domain. The scholar is credited for defining the scope and sphere of this emerging research domain. In this context, Geng et al. (2009) and Tan et al. (2016) were observed as the next most influential scholars, having significant bearings on the emerging paradigm shifts in the field of IS.

The emerging dimensions of industrial symbiosis research were observed more focused on minimizing the impacts of industrial production on environmental, social and economic capitals. These initiatives are incumbent for ensuring the conservation of natural resources and the resilience of socio-ecological surroundings.

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Conclusion

The field of Industrial Symbiosis (IS) is gaining acceptance for achieving the objectives through the integration of industrial production systems and collaborative research efforts. The current study revealed growing inclinations towards IS research. The findings protrayed that field is diversifying in scope and gaining acceptance from across the globe.

The outcomes of the study also depicted that industrial economies such as China, UK and USA are spearheading the domain of IS research. The plausible explanation for the growing orientations towards IS research in China can be the premise that the industrial growth remained steadier in this region. The research paradigm in IS are mainly concieved to ensure low carbon emission through research collaboration. The policy makers and researchers in China are stressing and promoting cross-country collaborations. The research paradigms in IS are mainly conceived to ensure low carbon emissions through resarch collaborations. More focused efforts will be required in the domain of IS to achieve the ultimate goal of clean and green industrial production in the face of mounting pressures from consumer-oriented life-style changes.

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