Paper submitted to:
R&D Management Conference 2018 *"R&Designing Innovation: Transformational Challenges for Organizations and Society"*
June, 30th -July, 4th, 2018, Milan, Italy

Innovation in eco-industrial parks: a comparative review of case studies

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Abstract: The innovation is a factor that influences the formation and development of industrial symbiosis complexes, through improvements in material utilization and reuse technologies, and the adjustment of industrial production structures. In the Circular Economy context, the innovation could be an effective strategy to improve the eco-efficiency. Based on the eco-industrial parks potential to support sustainable development and to be a platform of innovation in environmental management, this research aims to analyze the international scientific production of the case studies in eco-industrial parks and understand the how innovation is undertaken. It was developed a systematic review of literature. Data analysis was done in two stages: descriptive and exploratory. The co-word network maps were analysed through the VOSviewer software. The number of citations has grown in recent years. Most of the authors are from China, followed by the USA, and the main journal is Journal of Cleaner Production. Most of the EIPs are in China and more widely in Asia. Through the co-word analysis, we studied the conceptual structure of the research field. This research presented an overview that can guide academics and managers interested in EIP and innovation in the context of the parks.

1. Introduction

Long-term partnerships are essential so that organizations can make the transition towards sustainability, being necessary to have a systemic view to achieve sustainability (Geng et al. 2014). For such transition, theory and practice have made use of ideas and multidisciplinary practices to characterize the new organizational paradigm. In this context is the use of ecological terms, such as industrial symbiosis, which it aims the association on different stakeholders to generate benefits for all (Li et al. 2015).

One way to join the long-term partnerships with eco-efficient practices is through the construction of Eco-Industrial Parks (EIPs). EIP is "a park of industry corporations that collaborate with reusing waste and energy-efficient use of resources with no or small impact on the environment […] the industries are connected in closed loops through reuse and recycling of materials and waste" (Starfelt and Yan 2008, 1128).

The key word to describe the performance in EIPs is synergy (Chertow 2000) because, when seeking to partner, particularly in the business sector, we seek to generate even more value to the organization, so that the result that came from the sum of the agents involved (stakeholders) is greater than the individual results of each part. According to (Alvord 2003) the success of EIPs development is achieved by balancing the competing interests with a design that satisfies different stakeholders remaining viable.

The eco industrial development is positive for various agents of the production systems, such as companies where such development would offer new ways for profitable companies; the community where when there is a concern with the "eco" industries that become more rooted in the place of installation, creating better jobs and cleaner environment (Côté and Cohen-Rosenthal 1998). The importance of eco parks is given by the possibility that these create value in three ways and coverage levels: through marketing to the location that combines market and need for materials; through green buildings that preserve the operation of capital and increases productivity and property valuation and; by creating business networks that reduce operating costs, decreases stock and need for space and leads to market advantages (Cohen-Rosenthal and Smith 2003).

To Chertow (2003) and Chertow and Ehrenfeld (2012) the eco industrial development has the following objectives: efficient sharing of resources (synergy/symbiotic exchanges); economic gains and in environmental quality and; equitable enhancement of human resources for the business and local community.

Thus, the eco industrial development comes as a way of resolving issues related to job creation, urban redevelopment, response to complaints about brownfield, creation of an identity with the community, agricultural land revitalization and provision of adequate energy (Chertow 2003).

Based on the potential that the EIPs present to assist in achieving sustainable development, it is formulated the following research question: what is the panorama of international scientific research on eco-industrial parks? Given this context this research aims to analyze the international scientific production about the case studies in eco-industrial parks. And to achieve it, it was developed a systematic review of literature having as basis a consultation on articles published in journals indexed by Web of Science.

The innovation is a factor that influences the formation and development of industrial symbiosis complexes, through improvements in material utilization and reuse technologies, and the adjustment of industrial production structures (Zhang et al. 2014; Ehrenfeld and Gertler 1997; Roberts 2004). In the Circular Economy context, the innovation could be an effective strategy to improve the eco-efficiency of enterprises, improving the waste management, the efficiency of resource utilization and, the eco-design of products (Saavedra et al. 2018), "allowing generating more value and for a longer period" (Urbinati, Chiaroni, and Chiesa 2017, 487).

Based on the EIPs potential to support sustainable development and to be a platform of innovation in environmental management (Liu and Côté 2017; Shi, Tian, and Chen 2012), this research aims to analyze the international scientific production of the case studies in eco-industrial parks and understand the how innovation is undertaken.

2. Eco-Industrial Parks and Innovation

The concept of EIP forms along with the concept of symbioses Industrial (ISs), the body of industrial ecology (IE) (Lehtoranta et al. 2011; Wang et al. 2010). According to Frosch and Gallopoulos (1989), through imitation of the cyclic nature flows, the IS is responsible for reducing the consumption of natural resources, as well as the generation of waste. According to Aviso (2014), through the EIPs, the IE develops trade networks in order to promote the conservation of resources.

When it comes to sustainability it is observed the presence of the externality term, which it means that through regulation and compliance with these it is possible that companies internalize such externalities (Hendricks and Giannini-Spohn 2003). In median level of analysis, the local government becomes a relevant stakeholder, but in this case it comes to local governments, where it allows the construction of EIPs.

On a micro vision we have as the main stakeholder of eco industrial development the local community. There is a tendency to expand public participation on local communities in the decision-making process of the companies where these communities are benefited by the presence of the eco-industry (Hendricks and Giannini-Spohn 2003). Among the benefits from the relationship between the community and the EIPs, we can point: economic efficiency and profitability, retention of labor work and growth, community development, environmental management, capacity building and pride in community, social capital building, support the community through the acquisition of its resources.

The concept of eco-industrial park (EIP) used in this study supports the view from (Starfelt and Yan 2008, 1128), which understand as "a park of industry corporations that collaborate with reusing waste and energy-efficient use of resources with no or small impact on the environment […] the industries are connected in closed loops through reuse and recycling of materials and waste". Innovation is vital in the industrial symbiosis, which is one of the main aspects of EIPs, providing more profitable and faster results.

The first successful example of an EIP is the Kalundborg located in Denmark, which applies a symbiotic model since 1962 (Jacobsen 2003). Having the profitability as the main incentive for industrial symbiosis, the success of Kalundborg is due to the fact that the leaders made the right thing to the environment, even if it aims at their own business interests (Jacobsen 2003). The main conclusions drawn from the case of Kalundborg is that all agreements among several symbiosis partners are based on financially solid principles

and that a great composition of companies that are different and that are the right size might have a reducing effect of the overall environmental impact on the area in which they are allocated.

Based on the success of the first EIP performance suggests the need of open construction, the closed cooperation and mutual trust between the partners for the development of EIPs. Products developed in an industrial eco-park should be different and that symbiosis to be effective there must be a sharing of products by their characteristics should be geographically close.

3. Methodological Procedures

This research is characterized as a systematic literature review and considered for its formulation the Waddington et al. (2012, p. 360) "a systematic review has a clear protocol for systematically searching defined databases over defined time period, with transparent criteria for the inclusion or exclusion of studies, as well as the analysis and reporting of study findings".

To select the sample articles, it was used the tools of search ISI Web of Science database. The construction of search terms was made from the selection of key terms in the literature that matched the base "Eco + Industrial + Park." From them it was built the following search term: ("ecoindustrial" OR " eco industrial " OR "eco-industrial") (Topic) AND park * (Topic). It was chosen not to restrict the search period, in order to achieve all possible work referred on the subject, therefore it was used throughout the range of databases Web of Science (1864-2015).

In order to refine the search, the following criteria were used as filters:

a) databases: the basis chosen for the search of articles was the Web of ScienceTM Core Collection (Vitorino Filho et al. 2015; Affeldt and Vanti 2009; Cruz et al. 2015).
b) domains search: the base Web of ScienceTM Core Collection;
c) document types: it was chosen to check for Article, because it works peer reviewed;
d) language: it was decided to search for articles in English only.
e) terminology: it was decided to restrict the search to only papers that applied case studies. For this the result was refined by the presence of the following set of terms: ("case study" OR "case studies").

The articles found through search terms were submitted to the following exclusion criteria in order to refine the sample. Initially refinement was performed by reading the abstracts, being considered the following exclusion criteria.

a) exclusion of works dealing with industrial parks, Eco-Industrial Networks Low-carbon industrial parks or Resource Conservation Networks for not configuring the object of study.
b) exclusion of the works that did not develop a case study with the object studied;
c) exclusion of case studies that do not have the EIP as an object of study, but they referred application models, system or analysis and has as its object the eco-park;

The refined sample from these exclusion criteria underwent read the full text to perform the steps of the data analysis. For this reason, the studies were excluded from the full paper was unavailable. From reading the full paper, if the study did not present adherence to the research topic as well as the absence of the necessary elements for their classification, it would also be deleted.

3.1 Data Analysis

Data analysis was done in two stages. In the first stage, called as "descriptive analysis of articles", data were analyzed using one of content analysis techniques, known as categorical analysis (Bardin 1977; Govindan et al. 2015). Studies were classified into some specific categories: nationality of the authors, main authors, main journals of publication, year of publication, number of citations and most important articles in the sample. Besides that, the VOSviewer software was used in to analyze the co-word maps.

The VOSviewer software was developed in order to create, visualize and explore bibliometric maps of science (Van Eck and Waltman 2010). According to (Morris and Van der Veer Martens 2008; Van Eck and Waltman 2010) an important research topic in the bibliometric analysis field is the science mapping, as it has as objective to display the dynamic and structural aspects of scientific research (Börner, Chen, and Boyack 2003; Morris and Van der Veer Martens 2008; Noyons, Moed, and Luwel 1999).

4. Descriptive Analysis of Articles

The consultations were held in December 2017 and the initial search before the filters found 616 papers. After application of 3 from 4 filters 332 papers were reached. After applying the last filter, which was provided to search for studies that dealt on case studies, it had reached to 123 studies. The exclusion steps were performed as summarized in Table 1.

Table 1 - Deleting steps and final articles sample

Steps of Exclusion	Quantity of Found Papers
(=)Total articles found	**123**
(-)Articles eliminated by reading the abstracts	22
(-)Articles eliminated by reading the full paper	10
(=) Final Sample	**91**

The first step is to analyze the selected papers according categories in a descriptive analysis. The analyzed categories, as suggested by Govindan et al. (2015) and Jabbour (2013), are: nationality of the authors, main authors, main journals of publication, year of publication, number of citations and most important articles in the sample.

4.1 Publication per year

The first category analyzed is the publications per year. In this sense, the sample considered the papers published until 2017. Figure 1 shows the distribution of articles per year and it shows that the first case study was published in 2002. Moreover, it can be observed a growing trend in the number of publications in the last years, since almost 50% of papers were published after 2014. The year of 2017 is the one with most papers published, a total of 14 case studies. A hypothesis of this recently increase is that the studies about EIPs are at an emerging stage and the understanding of this movement is still under construction.

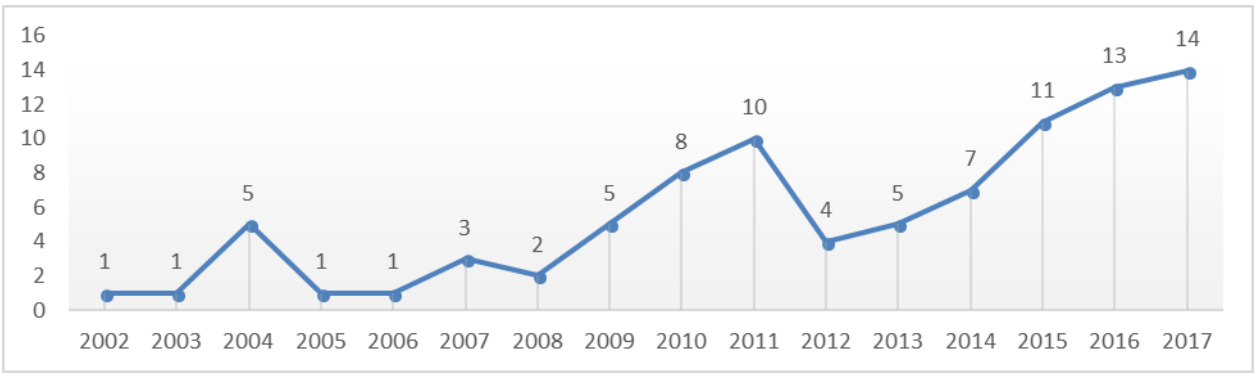

Figure 1 - Year of the articles analyzed

4.2 Analysis of authors

The first step of the authors' analysis was to consider the number of publications per author. Table 1 shows the names and absolute quantities of papers each author has published. Regarding the main researchers, it can be highlighted that some authors excel in the sample analyzed by providing a quantitative production superior to others. In total, the 91 articles have 258 authors, which means that each article has an average of

2.8 authors. Furthermore, four of these authors concentrate more than 30% of the publications: R. R. Tan, Y. Geng, Raymond P. Cote, and M. M. El-Halwagi.

Table 2- Main researchers sample

	Researchers	Quantity of Papers	Percentage
1	R. R. Tan	9	9.890
2	Y. Geng	8	8.791
3	R. P. Cote	6	6.593
4	M. M. El-Halwagi	5	5.495
5	K. B. Aviso	4	4.396
6	B. Chen	4	4.396
7	D. K. S. Ng	4	4.396
8	L. J. Chen	3	3.297
9	Z. J. Cui	3	3.297
10	A. B. Culaba	3	3.297
11	H. Kim	3	3.297
12	A. Mourtsiadis	3	3.297
13	H. Shi	3	3.297
14	L. Shi	3	3.297
15	J. P. Tian	3	3.297

All 9 papers from R. R. Tan had 175 citations (an average of 19,44 per paper). Y. Geng had 296 citations with his 8 published papers (an average of 37 per paper), while R. P. Cote had 308 citations with 6 papers (an average of 51,33 per paper). Last, with 5 papers, M. M. El-Halwagi had 115 citations (an average of 23 per paper).

The second category analyzed from the authors is the nationality. This category is considered important, once it reflects how much attention each country is giving to EIPs case studies. The analysis is presented in Figure 2, and shows that most of the authors are from China (44%).

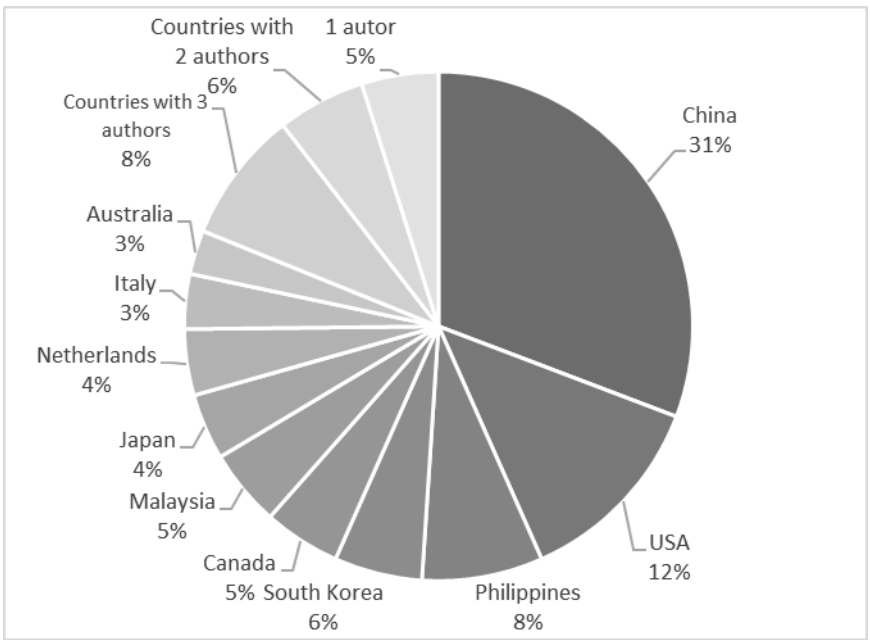

Figure 2 - Nationality of the authors of the sample

When the analysis is changed from the country of origin to the continent as the main criterion, the Asiatic predominance is even bigger, as it is shown in Figure 2. This is because, with this criterion, authors from Philippines, South Korea, Malaysia, Japan, Taiwan, Singapore and Vietnam join the Chinese.

4.3 Analysis of citations

Figure 3 shows the number of total citations of the sample articles in the referred years. Articles published 2010 are the ones with the higher number of citations (427), followed by the papers published in 2004 with 332 citations and the ones published in 2011 with 310 citations.

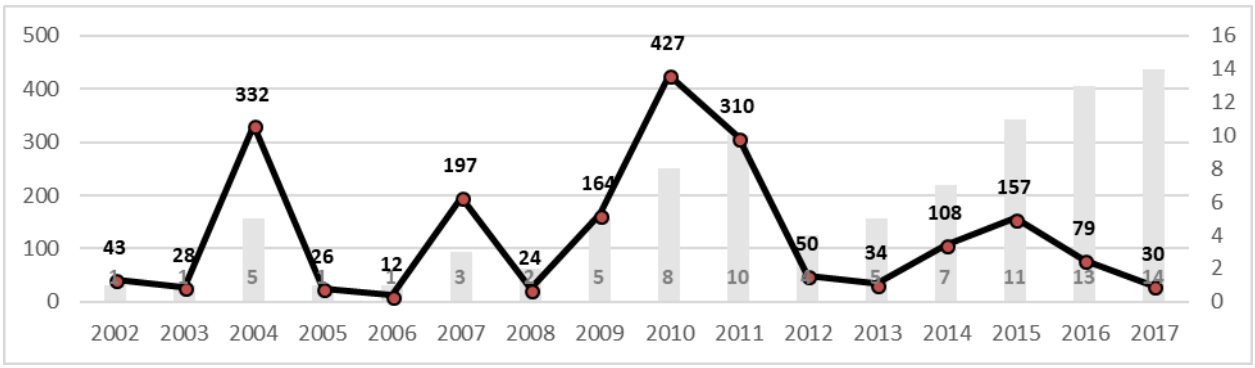

Figure 3 – Number of citations and number of publications

When combining information from Figure 3, it is possible to obtain the average of citations per paper each year, as seen in Figure 4. Unlike the analysis of absolute numbers, papers published in 2004 are the ones with the higher average of citation per article (66,4 citations per article), followed by articles published in 2007 (65,67 citations per article) and by articles published in 2010 (53,38 citations per year).

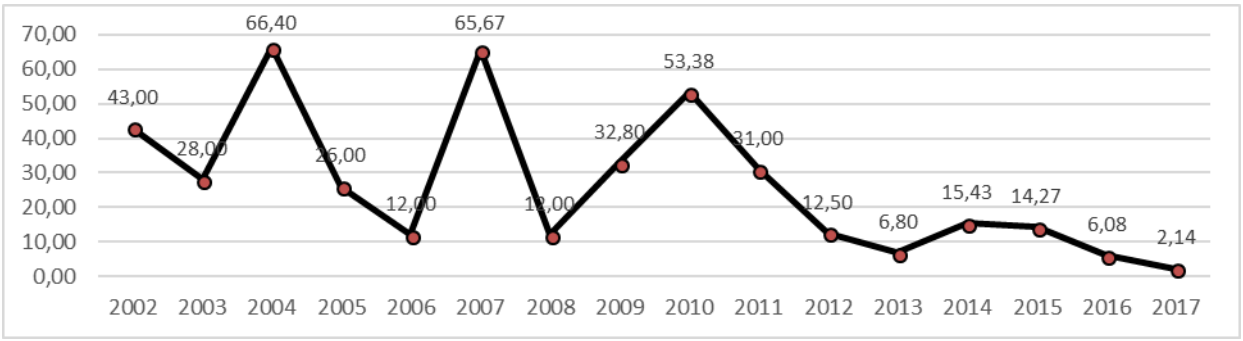

Figure 4. Citation Average Per Article

When considering the citations received by the articles each year, was possible to formulate Figure 5. As to the years pass by, the number of citations also increase, since more papers are published, which makes the absolute number of citations also to increase. The bars represent the variations in the numbers of citations from one year to another. The only period that presented a decrease in the quantity of articles was from 2012 to 2013. The higher increase in the number of citations was between 2014 and 2015.

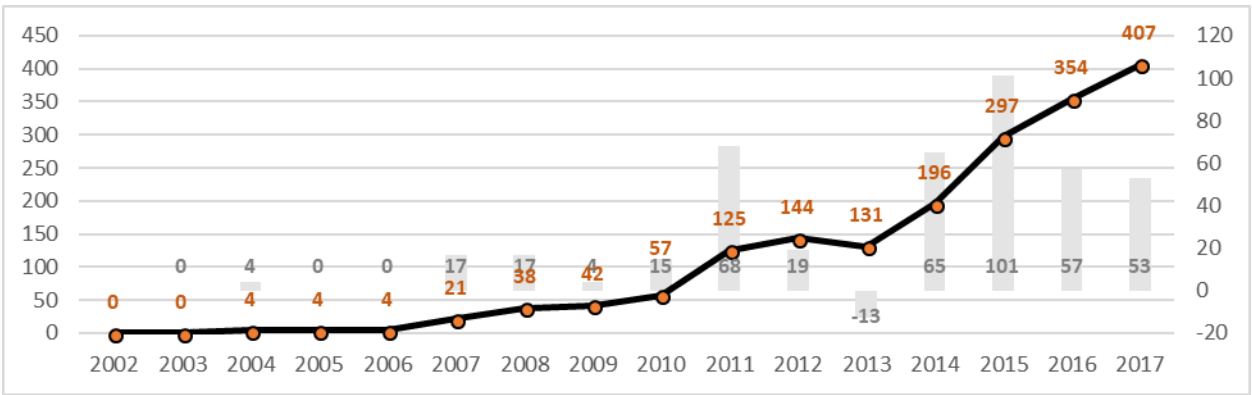

Figure 5 - Citations per articles each year

With the absolute numbers obtained in Figure 5 and the number of papers published (bars), it was calculated the citations average of each year, presented in Figure 6. In this figure it is possible to perceive that, although the light decrease in the average citation between 2015 and 2017, the citation average per article per year is increasing since the year of 2013.
The decrease seen in the year of 2013 can be explained by the decrease of the number of publications in the previous yea. Between 2011 and 2012, publications decreased from 10 to 4, which reflected in the year of 2013.

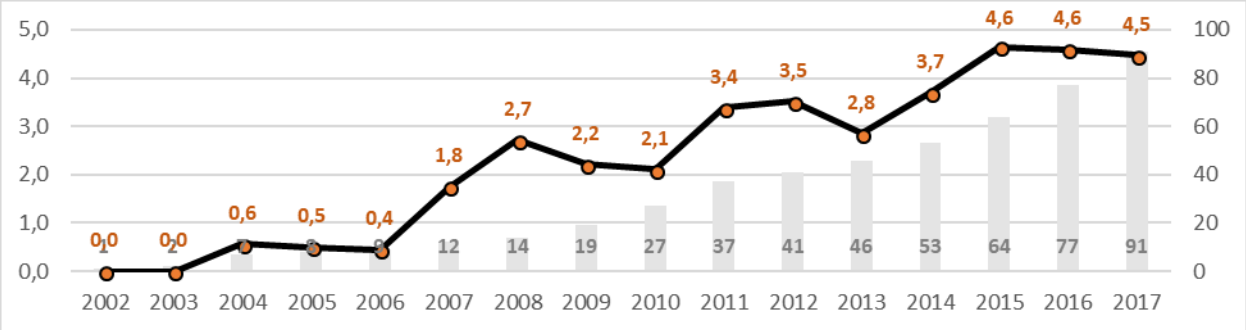

Figure 6 - Average of each year

Table 3 presents the top 10 papers with the highest averages of citation per year. Table 3 coantains the title of the article, the jornal of publication and the research fields, together with the total of citations and the average for each year of publications.
When analyzing the journal that these papers were published, it is noted that among the 10. 6 were published in the Journal of Cleaner Production, while 2 were published in the Journal of Industrial Ecology. The other 2 were published in Environmental Progress & Sustainable Energy and Science of the Total Environment. In relation to the year of publication, Figure 7 shows the distribution.

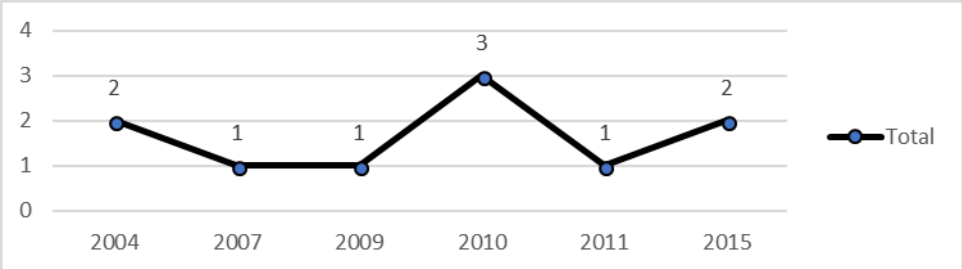

Figure 7 - Number of citation per year

Title	Authors	Journal	Research Areas	Year of Publication	Total of Citations	Average per Year
Developing country experience with eco-industrial parks: a case study of the Tianjin Economic-Technological Development Area in China	Shi, Han; Chertow, Marian; Song, Yuyan	Journal of Cleaner Production	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	2010	139	15,44
Progress Toward a Circular Economy in China The Drivers (and Inhibitors) of Eco-industrial Initiative	Mathews, John A.; Tan, Hao	Journal of Industrial Ecology	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	2011	89	11,13
Integrating green supply chain management into an embryonic eco-industrial development: a case study of the Guitang Group	Zhu, QH; Cote, RP	Journal of Cleaner Production	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	2004	140	9,33
Industrial symbiosis in China - A case study of the Guitang Group	Zhu, Qinghua; Lowe, Ernest A.; Wei, Yuan-an; Barnes, Donald	Journal of Industrial Ecology	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	2007	109	9,08
The application of industrial ecology principles and planning guidelines for the development of eco-industrial parks: an Australian case study	Roberts, BH	Journal of Cleaner Production	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	2004	132	8,8
Evaluation of innovative municipal solid waste management through urban symbiosis: a case study of Kawasaki	Geng, Yong; Tsuyoshi, Fujita; Chen, Xudong	Journal of Cleaner Production	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	2010	71	7,89
Design and Integration of Eco-Industrial Parks for Managing Water Resources	Lovelady, Eva M.; El-Halwagi, Mahmoud M.	Environmental Progress & Sustainable Energy	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	2009	77	7,7
Emergy analysis of an industrial park: The case of Dalian, China	Geng, Yong; Zhang, Pan; Ulgiati, Sergio; Sarkis, Joseph	Science of the Total Environment	Environmental Sciences & Ecology	2010	69	7,67
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	Wen, Zongguo; Meng, Xiaoyan	Journal of Cleaner Production	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	2015	30	7,5
Evolution of industrial symbiosis in an eco-industrial park in China	Yu, Fei; Han, Feng; Cui, Zhaojie	Journal of Cleaner Production	Science & Technology - Other Topics; Engineering; Environmental Sciences & Ecology	2015	28	7

Table 3 – The top 10 most cited papers

4.4 Analysis of Journals

When analyzing the journals of the publications of the sample, it was observed a concentration of about 45% (Figure 8) of publications related to case studies in EIP in three Journals. These journals, in descending order of representativeness with the respective absolute values of articles, are: Journal of Cleaner Production (29), Journal of Industrial Ecology (8) and, Clean Technologies and Environmental Policy (4).

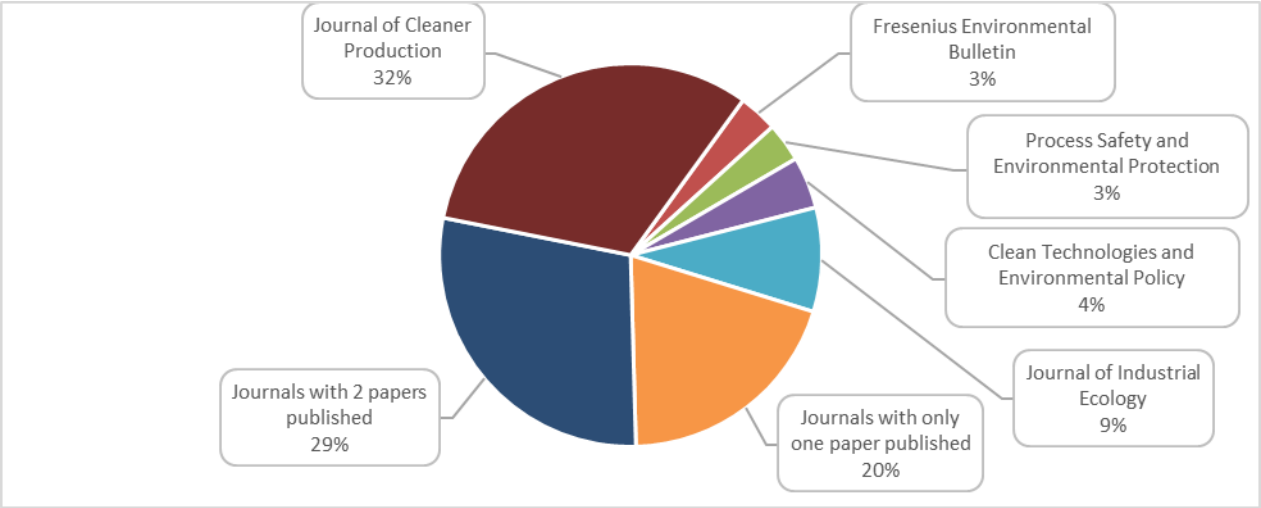

Figure 8 - Journals contained in the analyzed sample

Table 4 shows a list with 20 journals analyzing the citations of the papers until the day xx of June 2018. Colum 1 shows the sum of citations of the articles published by each jornal, while Colum 2 shows the division of the total of citations by the number of article, arriving to an average of the citations per article. Each paper of the sample has an average of citation per year, considering the year that was published (Table 3). In this sense, Colum 4 shows the average, not the total number of citations, but this average citation.

The journals in **Erro! Fonte de referência não encontrada.** are listed according to the citation average per year of its papers (Colum 4).

With only the absolute numbers of the sum of citations, the journals that point out are:: Journal of Cleaner Production (830 citations), Journal of Industrial Ecology (270 citations), Science of the Total Environment (93 citations), Journal of Environmental Management (90 citations) and Clean Technologies and Environmental Policy (79 citations).

However, when comparing the number of citations by article published, there is a significant change in the journals' positions. In the first position is Environmental Progress & Sustainable Energy, with an average of 77 citations per paper (one published paper). In the sequence there are: Science of the Total Environment (average of 46,5 citations per paper, two published papers) and Journal of Environmental Management (average of 45 citations per paper, two published papers), Applied Energy (average of 34 citations per paper, two published papers). At last, there is the Journal of Industrial Ecology, previously in the second position, now in the fifth with an average of 33,75 citations per paper, with eight papers, and the Journal of Cleaner Production, previously in the first position, now in the sixth with an average of 28,6 citations per paper, with twenty-eight published papers.

Nevertheless, the criterion used to ordinate Table 3 is presented in the last Colum of the table. This criterion was used, sice it takes into consideration, not only the quantity of papers responsible to generating the citations, but also the age of each paper (how many years they have been published and available to be cited. The journal with the higher annual citation average is the *Environmental Progress & Sustainable Energy* with 7,7 citations per year. The Journal of Industrial Ecology is in the seventh position with an annual average of 3,8 citations of each paper, while the Journal of Cleaner Production is in the ninth position with an annual average of 3,7 citations in its papers.

Journal	Total of Citations	Average of Citations	Contagem de Título	Média de Média por ano
environmental progress & sustainable energy	77	77	1	7,70
science of the total environment	93	46,5	2	5,17
journal of environmental management	90	45	2	4,75
applied energy	68	34	2	4,67
environmental science and pollution research	40	20	2	4,18
resources conservation and recycling	44	22	2	4,11
journal of industrial ecology	270	33,75	8	3,80
decision support systems	19	19	1	3,80
journal of cleaner production	830	28,62	29	3,70
environmental science & technology	38	19	2	3,64
aiche journal	13	13	1	3,25
industrial & engineering chemistry research	35	17,5	2	3,10
computers & chemical engineering	18	9	2	3,00
energy	9	9	1	3,00
ecological modelling	11	11	1	2,75
clean technologies and environmental policy	79	19,75	4	2,42
process safety and environmental protection	43	14,33	3	2,26
ecological economics	22	22	1	2,20
sustainability science	22	22	1	2,20
chemical engineering research & design	6	6	1	2,00

Table 3

4.5 Analysis of Research Areas

Each paper receives a classification from WoS according to its content Figure 9 illustrates the representativeness of each of these categories in the sample. 76.9% of the articles are in the Environmental Sciences Ecology category, while Engineering is applied to 63.7% of the sample and 56% are classified as Science Technology Other Topics. The remaining topics did not show relevance.

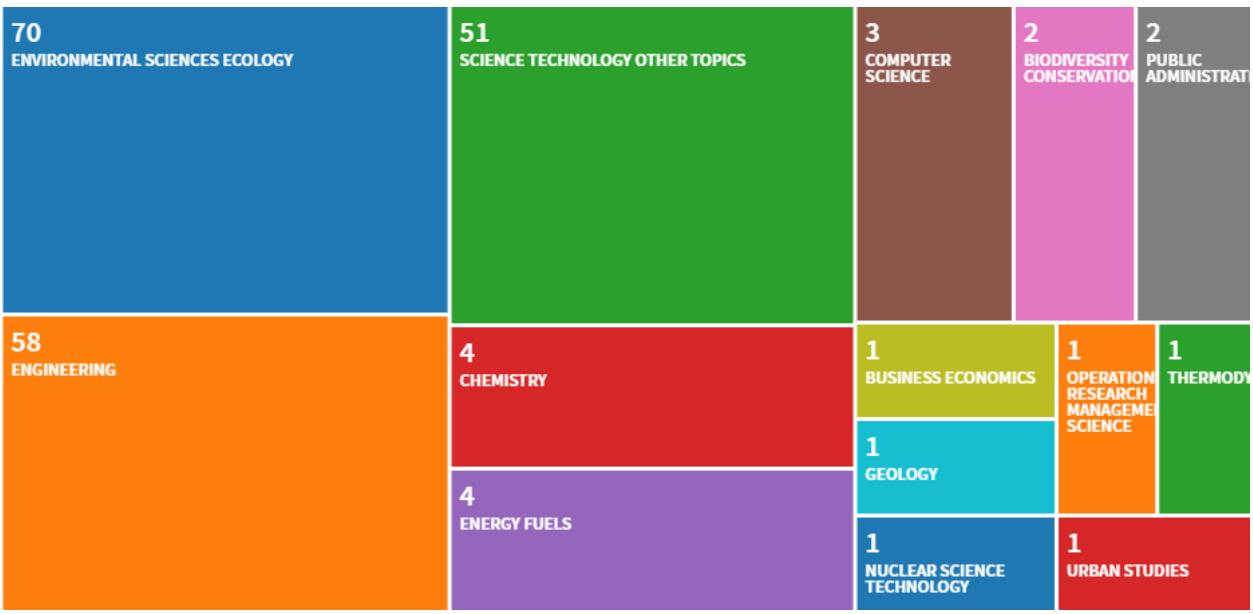

Figure 9 – Number of papers in each research areas

From the ten most cited papers presented in Figure 9**Erro! Fonte de referência não encontrada.**, nine of them are classified in these three categories simultaneously. Only the paper in the eighth category (Geng, Yong; Zhang, Pan; Ulgiati, Sergio; Sarkis, Joseph) is classified only in the Environmental Sciences & Ecology category.

4.6 Analysis of EIPs

The last analysis was the identification of EIP studied, which are detailed in Table 4.

Table 4 – identification of EIP studied and country

EIP Studied	EIP Country
Baotou	China
Beijing Economic Technological Development Area	China
Burnside Industrial Park	New Scotland
Daedeok Technovalley	South Korea
Dafeng / Lubei / Nanhai	China
Dalian Economic and Technological Development Zone	China
Debert Air Industrial Park	New Scotland
Dongguan Ecopark	China
Ecopark Hartberg / ValuePark Schkopau	Austria
Gangkou industrial park	China
Greek industry	Greek
Guitang Industrial Park	Denmark
Hefei economic and technological development area	China
Industrial Park of Herdersbrug	Belgium
Iskandar Oil Palm Eco-Industrial Park	Malasia
Japanese Eco-Towns	Japan
Jurong Island EIP	Singapore
Kalondborg Park	Finland
Kwinana Industrial Area-KIA	Australia
Lin-Hai Industrial Park	China
Macheon Industrial Park of Jinhae	South Korea
Marseille-Fos	France
National Economic & Technological Development Area	China
Ningdong Coal Chemical Eco-industrial Park	China
Porto Marghera industrial park	Italy
Poyang Lake Eco-Economic Zone	China
Qijiang Industrial Park	China
Qijiang Industrial Symbiosis	China
Shenyang Economic Technological Development Zone	China
Soc Trang	Vietnam
Suzhou Industrial Park	China
Synergy Park	Australia
Three Gorges	China
Tianjin Binhai New Area	China
Tianjin Economic-Technological Development Area	China
Ulsan Eco-industrial Park	South Korea
Yantai Economy Technology Development Zone EIP	China
Yeosu EPI	South Korea
Yixing Economic Development Zone (YEDZ)	China

In Table 4 along with EIPs countries where they are located are identified. Figure 10 makes it clear China's role in these case studies, as nearly 62% of the EIPs studied a/re located in this country, 47 in absolute numbers.

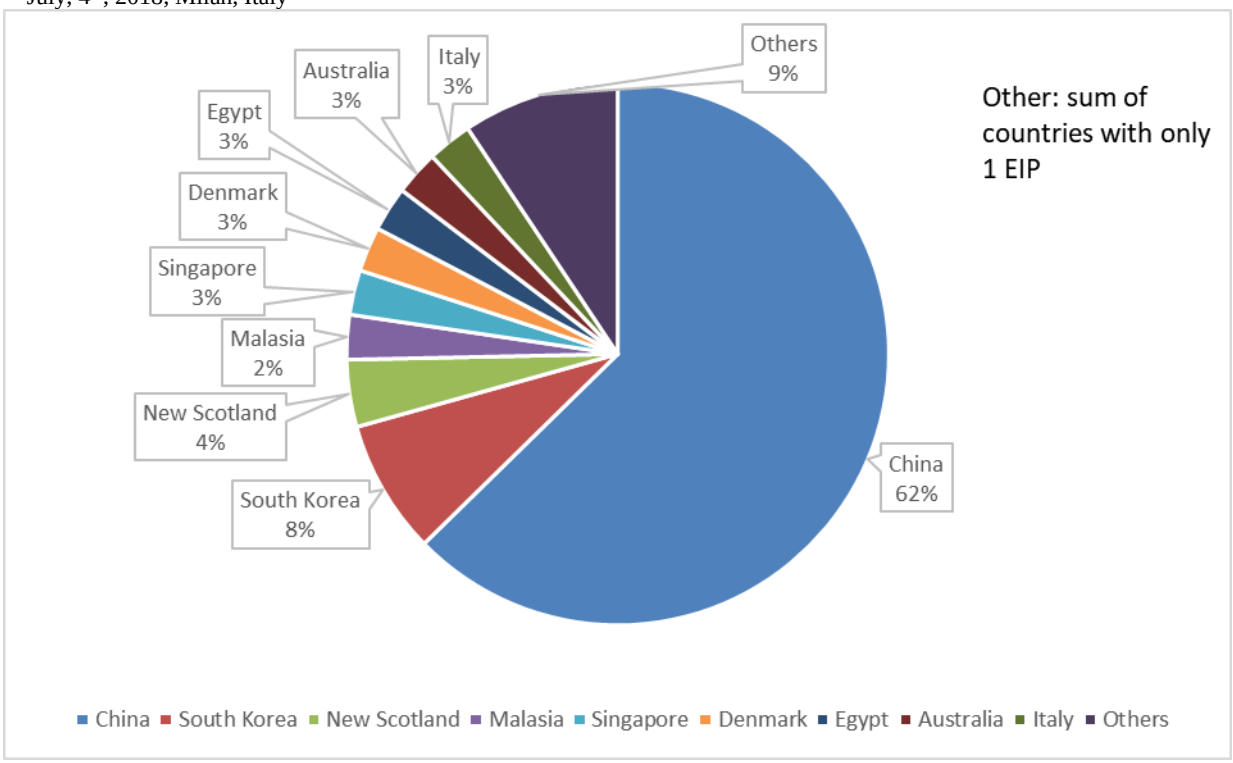

Figure 10 - EIPs per country

Another relevant aspect is that 80% of the EIPs are placed in Asia, 60 in absolute numbers. Outside this continent the second place with the most EIPs is Europe, with 10%, and the remaining are distributed in Oceania, America and Africa with average 3-4%, as shown in Figure 11.

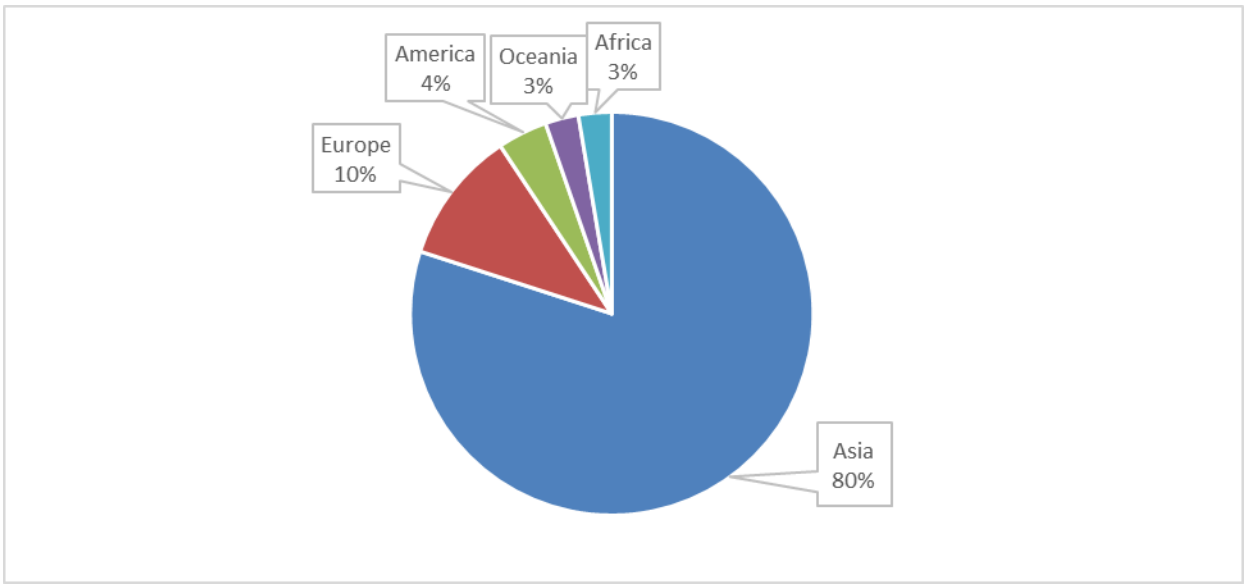

Figure 11 –EIPs per continent

Taking a better look in the most relevant country, besides the fact that more than 60% from all the EIPs Studied are placed in China, it's also relevant that there are a high diversity of EIPs in the studied cases. From the 47 total China ones studied, there are 20 different places.

5. Exploratory Analysis of Articles

5.1 Innovation

Considering the top 10 most cited papers listed in Table 3, regarding to innovation, it is commonly mentioned as an important aspect in the EIP. One of the articles talks about the management improvement in the EIPs practices, mostly on water reclamation and new soil sources.

It was also mentioned as a tool to reduce operational cost, such as transportation, resources of production and expansion. Besides that, it's also an encouragement for the development of new industries.
Innovation is vital in the industrial symbiosis, which is one of the main aspects of EIPs, providing more profitable and faster results.

Nevertheless, the innovation aspect is not very explored in the articles, it's usually mentioned as a important tool, but rarely explained in what aspect. Therefore, we can conclude that innovation is not the main focus from most of the papers related to EIPs.

5.2 Co-word analysis

The co-word analysis is a technique that is used to understand the strength of relationship between keywords and it measures through the co-occurrence of this words in the text. Stem from that, two different analysis were performed using the VOSviewer software to get a deeper understanding of which themes are arising from the sample.

In the first part, the software was counting the co-occurrence of all the keywords found in the articles, with full counting and a three times minimum occurrence. In this search were found fifty-five items that fit in the parameters and these items were formed seven clusters. The results are shown in the Figure 11 and Figure 12. The Figure 12 shows the density map of the clusters found.

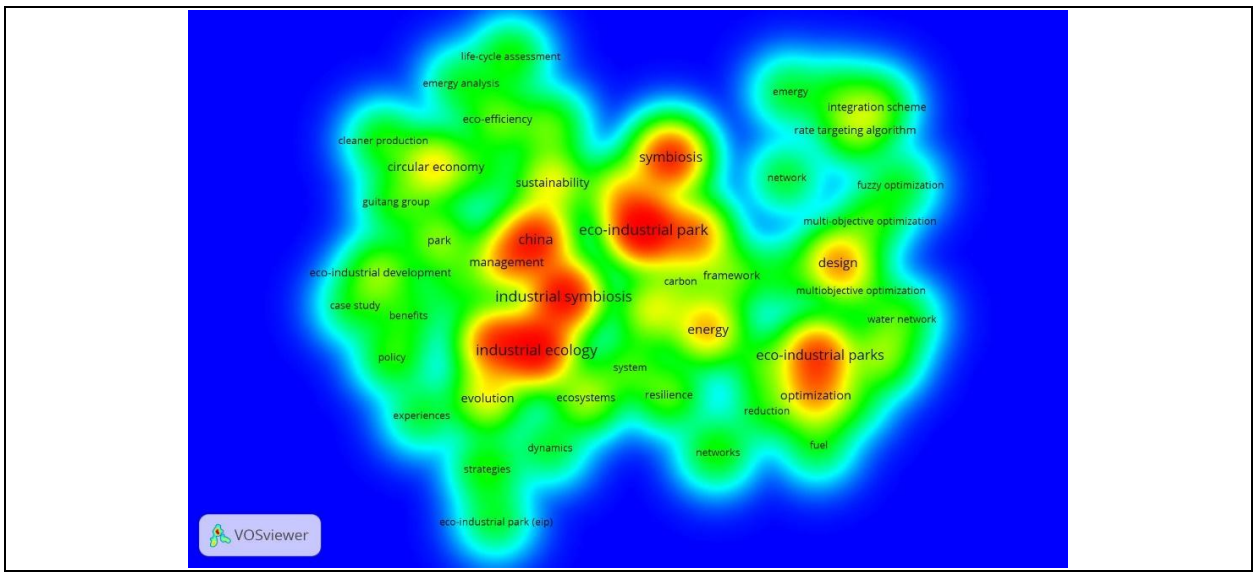

Figure 12 - Cluster density visualization

The Figure 13 shows the co-word network map, where the items are joined in clusters considering their linkages. Five cluster were formed with assorted colors: the red one is formed for 17 items, the green one has 13 items, the blue one has 13 items, the yellow has 7 items and, the pink one has items.

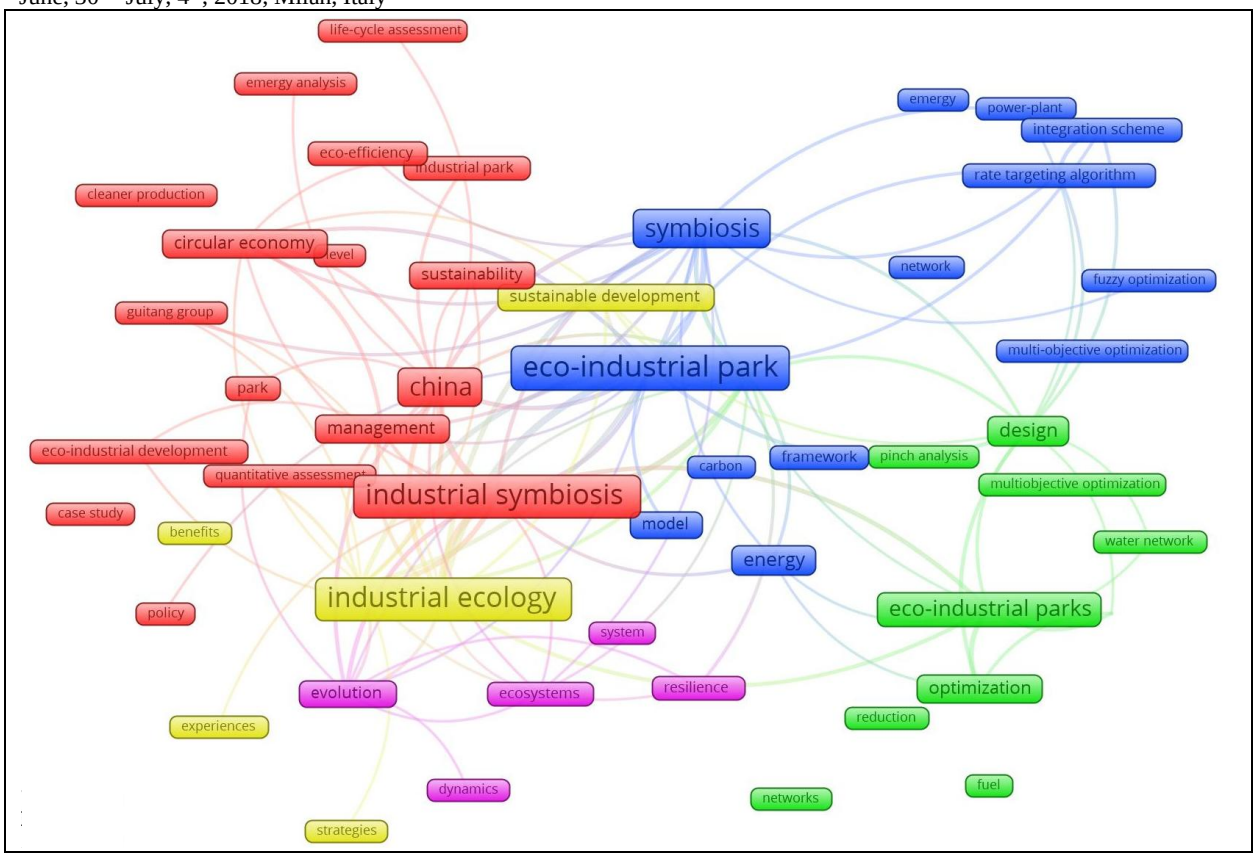

Figure 13 - Co-word network map

The list of the items in each cluster can be found in the Table 5.

Table 5 – Clusters description of co-word analysis

Color	RED	GREEN	BLUE	YELLOW	PINK
Items	Case study	Design	Carbon	Benefits	Dynamics
	China	Eco-industrial Parks	Eco-industrial Park	Eco-industrial Park - EIP	Ecosystems
	Circular economy	Emissions	Emergy	Ecology	Evolution
	Cleaner production	Energy Integration	Energy	Experiences	Resilience
	Eco-efficiency	Fuel	Framework	Industrial Ecology	System
	Eco-industrial development	Multi-objective optimization	Fuzzy Optimization	Sustainable Development	
	Emergy analysis	Networks	Integration Scheme	Strategies	
	Guitang Group	Optimization	Model		
	Industrial Park	Pinch Analysis	Multi-object Optimization		
	Industrial Symbiosis	Process Integration	Network		
	Level	Reduction	Power-plant		
	Life-cycle Assessment	Systems	Rate Targeting Algorithm		
	Management	Water Network	Symbiosis		
	Park				
	Policy				
	Quantitative Assessment				
	Sustainability				

To better understand the fields of study that arise, is important to develop an analysis of clusters, identifying main topics.

The first cluster is the red one, is the largest cluster, formado por 17 item. Some important items presented in this cluster are methods and aproachs aplicados nos EIP Cleaner production, life-cycle assessment, Eco-efficiency and

Circular economy. É preciso destacar a importância da China nesses cluster. Ela é o único país a aparecer nos cluster, reforçando o destaque que o país tem no tema. Li, Xiang hu, dong (2017), Wang deutz Chen and, wang, lu et al (2017) são alguns dos estudos da amostra que focam em estudar casos chineses e ainda olham por um perspectiva de Economia circular. No mesmo cluster está um importante EIP chinês, o Guitang Group. Os temos policy and Eco-industrial development estão ligados ao protagonismo chinês no desenvolvimento e aplicação de políticas visando o seu desenvolvimento industrial com menos impactos ambientais.

The second cluster é composto por thirteen items, the Green one. Apresenta destaque a otimização, sendo os modelos e ferramentas (pinch analysis, multiobjective optimization, mathematical programming, etc) são empregados para otimizar a utilização de recursos como o fuel and, principalmente, water. Regarding to water networks, these approaches have been used to identify optimal network designs. In general, the network designs seek the the generation of wastewater streams and reduce the use of freshwater (aviso, 2014, Aviso 2010, liang, shi, zhang, 2011, Taskhiri, tan, chiu, 2011).

The blue cluster tem o mesmo tamanho do Green Cluster, e também está ligado a ideia de otimização. No entanto os modelos e ferramentas são empregados para otimizar a utilização de recursos diferentes, ao invés de fuel and water, o recurso seria a energia. O foco continua em mathematical programming models as tools for optimizing the designs of networks, como nos trabalhos de Aviso, tan 2010, Taskhiri, tan, chiu, 2011, and, Kolluri 2016. Outros modelos também são frequentemente utilizados como rate targeting algorithm and multi-objective optmization.

5.3 Authors

In general the studies reviewed work under the theoretical approach of industrial ecology in order to seek efficiency gains, and preaches the seminal work from (Frosch and Gallopoulos 1989). However, the industrial symbiosis appears in articles (Geng et al. 2014; Lehtoranta et al. 2011; Yu et al. 2015; Zhang et al. 2015; Aviso 2014) as the theoretical core of the developed analysis. Still it was possible to identify some theories and secondary approaches in some studies, such as supply chain management (Cao et al. 2009) and Game Theory (Aviso et al. 2010).

Among the selected sample excel the articles that deal with the planning, design and development of EIPs (Zhu and Cote 2004; Roberts 2004; Oh et al. 2005; Kim 2007; Zhang et al. 2008; Cao et al. 2009; Liwarska-Bizukojc et al. 2009; Anh et al. 2011; Sakr et al. 2011; Geng et al. 2014; Mannino et al. 2015). Internal and external factors influence the creation of an EIP, having its development and progress dependent on strategic planning and conceptions made as well as the knowledge of the limiting factors and success (Mannino et al. 2015; Oh et al. 2005; Sakr et al. 2011).

As shown in the descriptive analysis, the Chinese authors quantitatively highlight in the production of case studies about EIP. Consequently, most of the studies was developed on EIP located in China. This role of China is highlighted in some studies that analyze eco industrial development practices (Geng and Cote 2004) or still the experiences of China with the EIPs (Matthews and Tan 2011; Wang et al. 2010). Initiatives such as the EIPs, came from the need for effective protection of the environment for a long-term development of industries (Cao et al. 2009; Wang et al. 2010). According to Cao et al. (2009), the urgency in environmental protection actions are reflections of accelerated economic growth, which it caused serious pollution problems and the impoverishment of natural resources.

All 9 papers from R. R. Tan had 175 citations (an average of 19,44 per paper). Y. Geng had 296 citations with his 8 published papers (an average of 37 per paper), while R. P. Cote had 308 citations with 6 papers (an average of 51,33 per paper). Last, with 5 papers, M. M. El-Halwagi had 115 citations (an average of 23 per paper).

All 9 papers from R. R. Tan aim the optimization of a mathematical model of an EIP. Most cases the author uses Linear Programming to solve a real problem from a non-identified EIP. The problems are focused mostly on water usage.
Based on the 8 articles from Y. Geng we can see that the aims from his researches are very diversified, including fields like innovation, recycling and management. Nevertheless, he has an operational perspective on most of his papers.

Half of the papers made by R. P. Cote were made with Y. Geng as well. Therefore, the objectives from his papers share the same aims from Gengs. Yet, sustainability and green supply chain are recurring themes in the researches.

M. M. El-Halwagis papers are focused on solving non-specific models (no EIP related to this cases) to find solutions from different fields in EIPs. These cases are mathematical models of the usage from different kind of chemical resources from the EIP operation.

According to Liang et al. (2011) the management of water resources is a critical element for EIPs in this sense we highlight a few items identified in the sample, as they analyze methodologies, systems, models and great designs for the management and sharing of these resources in EIPs (Lovelady and El-Halwagi 2009; Aviso et al. 2010; Yuan et al. 2010; Tan, Aviso et al. 2011; Taskhiri et al. 2011; Liang et al. 2011; Tan, Taskhiri et al. 2011; Aviso 2014).

Innovation is vital in the industrial symbiosis, which is one of the main aspects of EIPs, providing more profitable and faster results.

Nevertheless, the innovation aspect is not very explored in the articles, it's usually mentioned as a important tool, but rarely explained in what aspect. Therefore, we can conclude that innovation is not the main focus from most of the papers related to EIPs.

6. Final Considerations

The purpose of this article was to analyze the international scientific production about the case studies in eco-industrial parks. Therefore, it was performed a systematic review having as basis of consultation papers published in journals indexed to Web of Science.

Given the results found it was observed that it is a recent theme, since all the case studies identified were made from 2004, being the Journal of Cleaner Production the main journal that has published work referred to the topic of this study. Countries that exceled as theme researchers were China and secondly the US. The role of Chinese researchers reflected on the surveyed EIPs, and the vast majority of the objects of the case studies are located in China and more widely in Asia.

Following the role of China in this field of research, exploratory analysis showed that are presented in the sample works that purport to specifically study the Chinese policy of eco industrial development. Still as regards the exploratory analysis it was found that, in the case of a recent topic case studies are focused on analyzing the creation of EIP and also as they evolve and develop. Among these works, still excel studies that under efficiency preached by the industrial ecology approach, it is proposed to develop studies that seek enjoy the maximum water resources, considered critical to the EIPs.

As a limitation of this research it is the restriction of the search to a database (Web of Science), which may have reduced the sample and thus the possible conclusions. However, it points out that the sample included publications of the main journals of the area, thus showing, even if restricted, with high quality potential for such a study.

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