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Review

# The circular economy umbrella: Trends and gaps on integrating pathways

Aline Sacchi Homrich*, Graziela Galvão, Lorena Gamboa Abadia, Marly M. Carvalho

*Production Engineering Department, Polytechnic School University of São Paulo, São Paulo, Brazil*

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ABSTRACT

Among scholars, politicians and practitioners, the term "circular economy" (CE) has become increasingly familiar, but the concept comes from different epistemological fields and there is still a lack of consensus and convergence in the literature. This paper investigates the trends and gaps on the pathways convergence of the circular economy literature. The research method is a combination of semantic analysis, bibliometrics, networks and content analysis in a systematic literature review. The sample is composed of 327 articles extracted from the Web of Science and Scopus database. The results point out the lack of consensus on terminologies and definitions, thus, based on semantic analysis, a definition is proposed. In addition, the literature shows two main clusters, with different backgrounds, of different leading research groups in distinctive geographic regions. One cluster focuses on ecoparks and industrial symbiosis, mostly in the context of China. The second cluster is concerned with supply chains, material closed loops and business models.



**Contents**



* Corresponding author. Av. Prof Almeida Prado,128, Travessa 2, Bloco G 2, 2nd Floor, Cidade Universitária Butantã 05508900, São Paulo, SP Brazil.
*E-mail address:* alinesacchihomrich@gmail.com (A.S. Homrich).

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## 1. Introduction

In the academic world, among politicians, and practitioners of real-life industrial operations, the term “circular economy” (CE) is being more frequently mentioned. Circular economy can be understood as “an idea and ideal” (Gregson et al., 2015, p.218) for facing the increasing limitations of Earth's natural resources (Meadows et al., 2004), facing the limitations as a new path to the transition to production and consumption for sustainability (Cooper, 2005).

Circular economy enables cyclical thinking, instead of having an open-ended conception of the value-added chain (Wuebbeke and Heroth, 2014), looking for “closed loops” (Bocken et al., 2016), or minimizing the consumption of virgin materials and energy (Wuebbeke and Heroth, 2014). However, “CE is emerging as an economic strategy rather than a purely environmental strategy”(Yuan et al., 2006), requiring a “complete reform of the whole system of human activity, which includes both production processes and consumption activities” (Yuan et al., 2006). The industrial structure and industrial policies reform must be adjusted to promote new technologies development in order to reach a solution by changing the waste recycling focus (Yuan et al., 2006; Tu et al., 2011).

Although the expression “circular economy” still remains open, in general it must include at least the notion of inputs reduction, reuse, and recycling waste; this naturally creates the necessity of optimized networks between companies and eco-industrial parks (Yu et al., 2013), exemplified by industrial symbiosis and extended product life (Gregson et al., 2015, p.218). In turn, the concepts within industrial ecology, such as cradle-to-cradle can be considered leading principles for eco-innovation, in which wastes are used as raw materials for new products and applications known as “zero waste economy” (Mirabella et al., 2014).

In order to move towards this new path, circular supply chain management (CSCM) is crucial, to enable new business models for the circular economy (Bocken et al., 2014) through the closing, narrowing and slowing of loops (Bocken et al., 2016). Product lifecycle thinking is fundamental from the beginning, from the design of the goods being manufactured, to ensure favorable and enabling conditions for disassembly and adaptation for reuse. This is also reflected in an alternative economic mindset based on reconditioning, remanufacturing and recycling (Gregson et al., 2015).

It is possible to say that the terminology around “circular economy” has been diverging rather than converging, and the term “closed loop” is often used in parallel (Bocken et al., 2016). Some authors also say that CE is a concept that emerged from the industrial ecology paradigm and has a closing-loop notion as its original central idea. (Yuan et al., 2006). In addition, distinctive research streams coming from different epistemological fields like biology, economy, and ecology provide a conceptual umbrella such as cradle-to-cradle (McDonough and Braungart, 2002), industrial ecology (Graedel and Allenby, 1995), and biomimicry (Benyus, 2002).

The present study aims to narrow the identified gap by performing a mapping study, analyzing the emergent literature on the circular economy from different fields, and exploring a large sample of publications. To accomplish this objective, this paper seeks to answer the following research questions:

- *(RQ#1) What are the main research streams, the core topics, authors, and journals?*

To achieve a more complete and inclusive understanding, based on the findings from this first question, the main definitions on circular economy are identified and used to develop a more comprehensive one, by answering the second research question:

- *(RQ#2) What is the definition of circular economy?*

To further analyze the circular economy content, the most recent ideas from this research area and identify future research agendas, the third question is proposed:

- *(RQ#3) What is the most up-to-date thinking, trends and gaps in the literature?*

To answer these questions, the research design merges semantic analysis, bibliometrics, network and content analysis in a systematic literature review. The paper is organized in six sections. Section 2 outlines the concept of CE and its theoretical foundations, followed by Section 3, which presents the research design. In Section 4, the results are presented by analyzing divergences in terminology around circular economy, applying bibliometrics, semantic analysis to present a comprehensive definition of CE, followed by the content analysis to answer the research questions. Sections 5 and 6 present the discussion and conclusions.

## 2. Literature review

The introduction of the concept of circular economy is associated with Pearce and Turner (1990) as mentioned in the papers of the following authors: Su et al. (2013); Ghisellini et al. (2016) and Geissdoerfer et al. (2017). They investigate the influence of natural resources on economic systems and the impacts of linear and open-ended perspectives.

Among firms and practitioners, the concept of circular economy has been disseminated by the Ellen MacArthur Foundation as “an industrial system that is restorative or regenerative by intention and design” (MacArthur, 2015) and driven by four principles: (i) waste is equal food; meaning that restorative loops is the central idea, (ii) building resilience through diversity, (iii) creating energy from renewable resources, and (iv) thinking in systems. To understand the closed loop concept, a butterfly diagram illustrates the two butterfly wings: the right is the technical and the left the biological closed loop (MacArthur, 2013).

However, from the academic perspective, there is a lack of consensus and various definitions of circular economy coexist, as discussed further in this paper and summarized in Appendix A. The most frequent research streams that refer to the foundation of CE are presented in Table 1. The concept of closed loops is one of the most frequently mentioned aspects related to CE; biological loops are more aligned to environmental and biology backgrounds, while technical closed loops are more aligned to economic and industrial perspectives. More recently, the fields of management and strategy are paying more attention to CE with a growing literature on circular business models (Linder and Williander, 2017; Lewandowski, 2016; Bocken et al., 2016).

With so wide a range of theoretical influences from different epistemological fields such as economy, biology, and environment, it is hard to achieve a consensus about what CE really is. This is what motivates this study.

## 3. Research methods

The research design combines quantitative and qualitative strategies. It merges bibliometrics, semantic and content analysis because these methods are complementary (Carvalho et al., 2013). Owing to the great number of academic publications, bibliometric

**Table 1**
Schools of thought of CE.

| Schools of thought | Definitions | Source | References that link with CE |
|---|---|---|---|
| Cradle-to-cradle | Products designed to regenerate the ecosystem as biological nutrients or to regenerate industries such as nutrients, components and materials in a 100% closed material loop. | McDonough and Braungart (2002) | Geissdoerfer et al. (2017), Lewandowski (2016), MacArthur (2015), Scott (2013). |
| Industrial ecology | Cyclical resource-use patterns observed in biological ecosystems are used as a model for designing mature industrial ecosystems, whose productivity depends less on resource extraction and waste emission. | Graedel and Allenby (1995) | Geissdoerfer et al. (2017), Lewandowski (2016), MacArthur (2015), Scott (2013). |
| Biomimicry | Designers are inspired directly by organisms, biological processes and ecosystems. | Benyus (2002) | Geissdoerfer et al. (2017), Lewandowski (2016), MacArthur (2015), Scott (2013) |
| Laws of ecology | They are four: (i) everything is connected to everything Else, (ii) everything must go somewhere, (iii) nature knows best and (iv) there is no such thing as a "free lunch". | Commoner (1971) | MacArthur (2015). |
| Performance economy | It enables entrepreneurs to achieve a higher competitiveness with greatly reduced resource consumption and without an externalization of the costs of waste and of risk. | Stahel (2010) | Geissdoerfer et al. (2017); Lewandowski (2016), MacArthur (2015), Scott (2013). |
| Blue economy | The need to find a way of meeting the basic needs of the planet and all its inhabitants with what the Earth. | Pauli (2010) | Geissdoerfer et al. (2017); Lewandowski (2016), MacArthur (2015), Scott (2013). |
| Regenerative design | This means replacing the current linear system of transfer flows with cyclical flows at sources, consumption centers and sinks. | Lyle (1996) | Geissdoerfer et al. (2017); Lewandowski (2016), MacArthur (2015), Scott (2013). |
| Permaculture | It is an integrated evolutionary system of perennial or self-perpetuating plant and animal species useful to man, it is a complete agricultural ecosystem. | Mollison and Holmgren (1978) | Lewandowski (2016), MacArthur (2013), |
| Natural capitalism | An approach that protects the biosphere and improves profits and competitiveness. Some changes in how to run the business, based on advanced techniques to make resources more productive, can yield amazing benefits for both current and future generations. | Lovins et al. (1999) | Lewandowski (2016), Scott (2013). |
| Industrial metabolism, Industrial symbiosis and Ecoparks | The use of matter and energy in the economic system shows certain parallels with the use of matter and energy by biological organisms and ecosystems. Industrial symbiosis is a merger of two or more different industries, where each industry tries to find optimal access to material components and material elements. | Ayres (1989); Renner (1947) | Geissdoerfer et al. (2017), Lewandowski (2016), Scott (2013). |

studies are being more accepted and bibliometrics is being recognized as a systematic and relevant approach (Ikpaahhindii, 1985; Neely, 2005). The content analysis allows an in-depth understanding of the research constructs and their relationship (Duriau et al., 2007), while the semantic analysis can help in establishing definitions and narrative scenarios (Carvalho et al., 2013). The aim is to outline major lines of research in the field, as well as to trigger further research (Seuring and Müller, 2008).

Aligned with the research objectives of mapping the literature on circular economy, a systematic literature review (SLR) approach was selected to answer the three research questions (RQs) as highlighted in the introduction section. The whole research flow is presented in Fig. 1.

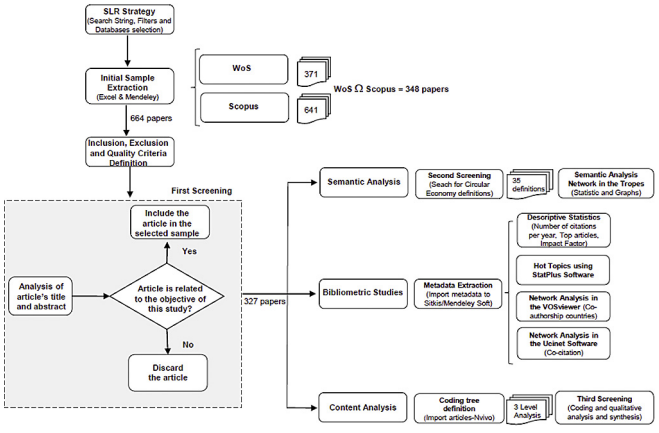


**Fig. 1.** Systematic literature review workflow.

### 3.1. Sampling procedures

Data was obtained from the scientific databases, ISI Web of Knowledge, Web of Science Core Collection and Scopus, by late December 2016. The selection criteria for these databases were the quality and quantity of publications; thus ISI Web of Science was selected because it can reach all indexed journals with a calculated impact factor in the JCR (Journal Citation Report) (Carvalho et al., 2013) and Scopus was selected because it is the largest database of peer-reviewed literature (Morioka and de Carvalho, 2016). In addition, both databases provide compatible metadata for bibliometric analysis software, carrying the articles' respective abstracts, references, citation indexes, authors, institutions, countries, among others (Carvalho et al., 2013).

The only filter applied was "type of documents", choosing only "articles", "reviews" and "articles in press" (the last one only in the Scopus database) because of the robustness of the pairwise review process (Takey and Carvalho, 2016). The search string used was "circular economy", applied as a "topic" in Web of Science, and in Scopus the same search string was applied for "article title, abstract and keyword". 371 articles in the ISI Web of Science (WoS) and 641 articles in Scopus were found. Within this amount, 348 articles were duplicated (found on both databases). The initial sample analyzed was composed of 664 articles (371 WoS + 641 Scopus − 348 WoS Ω Scopus); these were then imported to Mendeley

**Table 2**
Research questions and methods.

| # | Research Question | Method | Software |
|---|---|---|---|
| 1 | What are the main research streams, the core topics, authors, and journals? | Bibliometrics and Network Analysis | Sitkis, Access, Ucinet, NetDraw, Minitab, Excel VOSViewer |
| 2 | What is the definition of circular economy? | Semantic Analysis | Tropes |
| 3 | What is most up-to-date thinking, trends and gaps in the literature? | Content Analysis | NVIVO |

software (Butros and Taylor, 2010) for the first screening based on the analysis of the titles and abstracts. In the screening process, the researchers analyzed each selected publication separately to assess its compliance with the paper selection criteria based on the publication focus and its fit with the research questions, and quality criteria related to the methodological quality of the publications, as suggested in the literature (Carvalho et al., 2013). An article was excluded by the researchers' consensus; if agreement was not unanimous, the article remained in the sample for further analysis. The first screening process resulted in a refined sample of 327 articles.

### 3.2. Data analysis

To manage the sample, Mendeley software (Butros and Taylor, 2010) was used, and the Microsoft Access database allowed the metadata generated by Sitkis software to perform further analysis. To answer the three research questions (RQs), three methods were used in the SLR as shown Table 2.

First, to answer RQ#1, bibliometrics and network analysis were applied. Three types of social networks were designed: keywords, article to references and co-citations. Sitkis software version 2.0 (Schildt, 2006) was used to perform the relational matrix, relating to the metadata of the selected sample, the Excel, Access and Ucinet for Windows 6.289 program(Borgatti et al., 2002) to encode the relationships and NetDraw to illustrate the relationship diagrams. Furthermore, an overview of the evolution of publications per year, main journals, and authors in this research field is presented, based on descriptive statistics of the general sample, applying additional software, such as Minitab 17 (Minitab, 2014), and for country analysis the VOSViewer (Eck and Waltman, 2010).

The semantic analysis (Carvalho et al., 2013; Wang and Tsai, 2009) was applied to answer RQ#2. The selected sample was screened for identifying definitions of "circular economy" and the main cited references for definitions such as that from the Ellen MacArthur Foundation were identified and analyzed as detailed in Appendix A. Semantic analysis involves analyzing syntactic structures and textual context in a selected sample (Wang and Tsai, 2009), thus, just definitions in the English language were analyzed, applying Tropes v.8 software (Molette and Landre, 2010).

The content analysis was used for answering RQ#3, based on an in-depth analysis of the core papers (Mayring, 2014; Seuring and Müller, 2008; Tranfield et al., 2003). The core papers are defined by the combined analysis of the outliers, i.e., the papers that have the average citation higher than the expected spread in boxplot analysis (see Fig. 4), and the impact factor (Equation (1)). According to Seuring and Müller (2008), the content analysis may be oriented by a deductive or an inductive approach. The content analysis research protocol combines the recommendations of Tranfiled et al. (2003) and Duriau et al. (2007) in the following steps: (i) planning the review (research questions, search strategy and coding), (ii) conducting the review (frequency counts and cross-tabulations), and (iii) reporting and disseminating (interpretation of results). The NVivo software (Bazeley and Jackson, 2013) was used to help the coding process of the sample. The codes tree applied in the content analysis is presented in Table 3.

For the research methods analysis, the codes tree was defined as suggested by Carvalho et al. (2013), applying a mix of deductive approach based on the theoretical background and insights of bibliometrics. This paper uses insights extracted from the keywords and the hot topics analysis. First, the triple bottom line (TBL) codes, as proposed by Elkington (1997), were applied to each paper according to one perspective (environment, social or economic) or a combination of them. Second, the codes for the circular economy approach included three main loops as follows: slowing (Stahel, 1994, 1997), closing (McDonough and Braungart, 2010) and narrowing material flow (Braungart et al., 2008; Bocken et al., 2016). Slowing the resource loop, according to Stahel (1994), would be the extension of a product's life. McDonough and Braungart (2010) explain the closing of a loop as the ideas of post-use and recycling. Narrowing the resource loop as suggested by Braungart et al. (2008) would be through a more efficient use of environmental resources. Bocken et al. (2016) also discuss the necessity of using the three approaches in a balanced way to implement a real circular economy.

Third, the industrial ecology and symbiosis codes were deployed as follows: transaction costs (Su et al., 2013; Hsu, 2013), symbiosis (Chertow, 2000; Li et al., 2015), externalities (Dahlman, 1979), and partnership and alliance (Barber et al., 2012). Transaction costs refer to the organizational attempt to minimize the internal costs of managing exchanges, and the costs of exchanging resources in the environment (Choi and Krause, 2006). According to Chertow (2000), industrial symbiosis consists of physical exchanges among different entities of "materials, energy, water, and by-products". The externalities concept (Dahlman, 1979) adopted in this analysis is the consequence of an economic activity, production or consumption of a specific good, having an impact on a third party that is not directly related to the production or consumption of that

**Table 3**
Content analysis codes tree.

| Research Method | TBL | CE Approach | Main Issues |
|---|---|---|---|
| Conceptual Research | | | |
| Literature Review | Environmental | Slowing the Loop | Symbiosis |
| Simulation or Theoretical Modeling | Economic | Closing the Loop | Trasactional Costs |
| Empirical Research | Social | Narrowing the Loop | Externalities |
| Survey | Environ + Economic | | Partnership/Alliance |
| Case Study | Environ + Economic + Social | | |

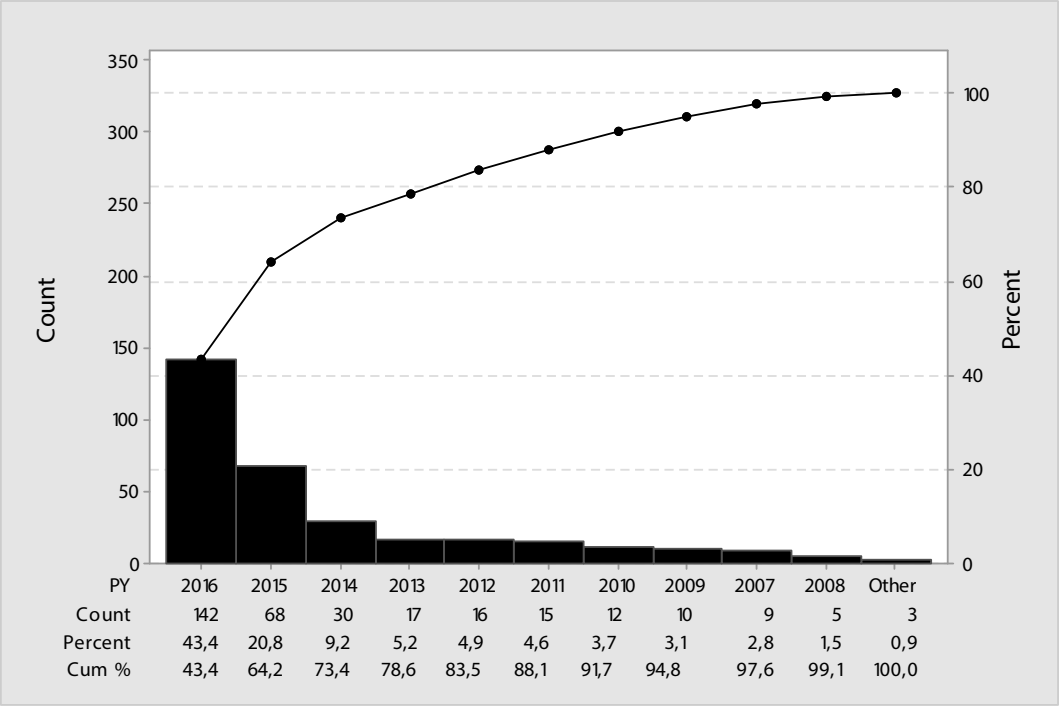


**Fig. 2.** Year Pareto chart for CE publications.

good: pollution, for instance. The idea of partnership and alliance adopted in the study is the interaction between organizations cooperating to reduce waste and energy use in developing and implementing a product, and also in pollution preventive processes (Vachon and Klassen, 2006).

## 4. Results

### 4.1. Literature panorama: evolution, core journals, authors and topics

An initial literature overview based on descriptive statistics of the sample was performed. Pareto chart was applied to show the yearly contribution. It is a bar chart in which the horizontal axis represents attributes of interest, in our case years, by ordering the bars from the largest to the smallest occurrence, and a cumulative percentage line helps to judge the added contribution of each category (year). Fig. 2 shows the yearly evolution of circular economy publications, highlighting that 73% of the sample was published in the last three years (2014–2016), and the number of publications has more than doubled yearly since 2013, showing a very rapid increase of interest in this subject in recent years. The oldest publications found in WoS were published in 2006 and in Scopus in 2001.

**Table 4**
List of the most cited papers.

| Authors | Article Title | Journal | Average Citations | JCR/IF[a] | AIF |
|---|---|---|---|---|---|
| Peters,Weber, Guan, Hubacek | China's growing CO(2) emissions - a race between increasing consumption and efficiency gains | Environmental Science & Technology | 23.91 | 6.198 | 172.1042 |
| Huang, Guo, Xu | Recycling of waste printed circuit boards: A review of current technologies and treatment status in China | Journal of Hazardous Materials | 21.33 | 6.065 | 150.6965 |
| Mirabella, Castellani, Sala | Current options for the valorization of food manufacturing waste: a review | Journal of Cleaner Production | 24.00 | 5.715 | 161.1600 |
| Shi, Chertow, Song | Developing country experience with eco-industrial parks: a case study of the Tianjin economic-technological development area in China | Journal of Cleaner Production | 13.88 | 5.715 | 93.2042 |
| Zhang, Ding, Zhang, Chen, Ding, van Loosdrecht, Zeng | Fatty acids production from hydrogen and carbon dioxide by mixed culture in the membrane biofilm reactor | Water Research | 7.40 | 6.942 | 58.7708 |
| Chertow, Ehrenfeld | Organizing self-organizing systems | Journal of Industrial Ecology | 14.67 | 4.123 | 75.1544 |
| Geng, Fu, Sarkis, Xue | Towards a national circular economy indicator system in China: an evaluation and critical analysis | Journal of Cleaner Production | 13.00 | 5.715 | 87.2950 |
| Xi, Geng, Chen, Zhang, Wang, Xue, Dong, Liu, Ren, Fujita, Zhu | Contributing to local policy making on GHG emission reduction through inventorying and attribution: a case study of Shenyang, China | Energy Policy | 7.86 | 4.141 | 40.4083 |
| Zhang, Yuan, Bi, Zhang, Liu | Eco-industrial parks: national pilot practices in China | Journal of Cleaner Production | 7.12 | 5.715 | 47.8108 |

Note: Papers in descending order of article impact factor (AIF).
[a] JCR/IF (2016).

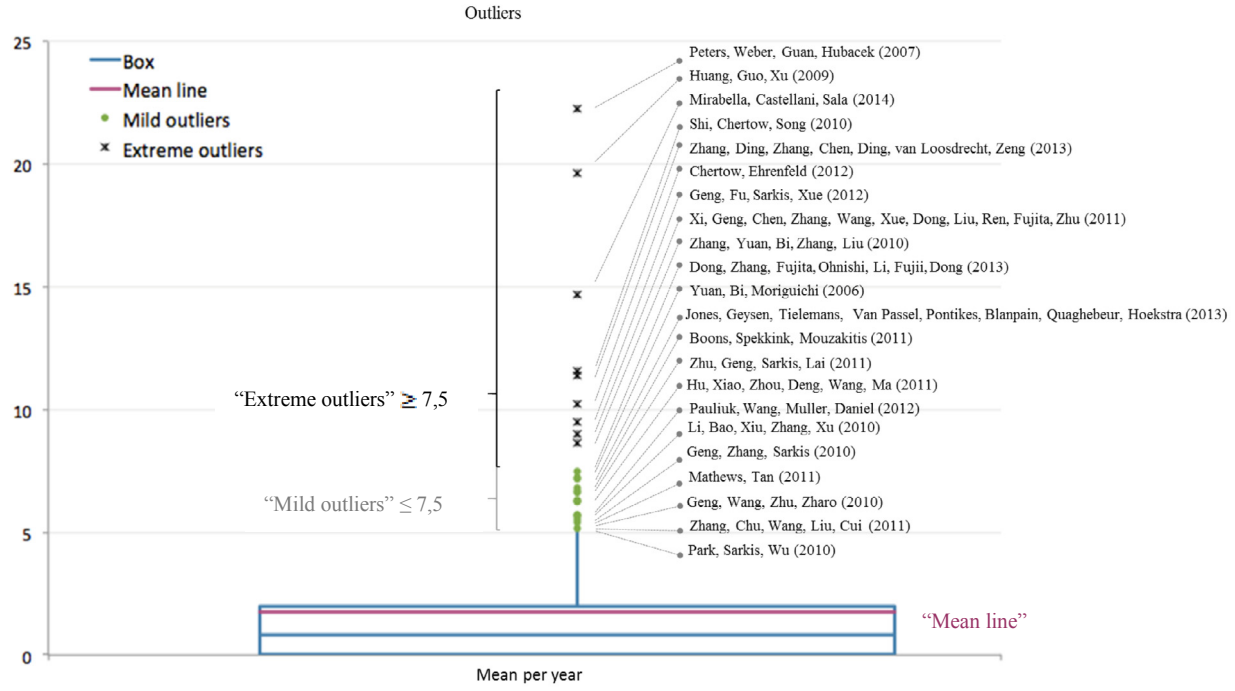


**Fig. 3.** Articles outliers in number of citations from the CE sample *Note: Papers in descending order of citations.

The six journals that most published papers on CE represent 44% of the total sample. The first of these is *The Journal of Cleaner Production*, which is the main source of publications on CE (75 papers) and has the most varied scope on the topic, having more technical papers on recycling and other related issues towards sustainable business models. The second is *Resources Conservation and Recycling* (20 papers), which has a diverse content of subjects linked with CE. *The Sustainability Journal* is the third with 19 papers, mostly regarding ecoparks and industrial symbioses discussions on the supply chain. The fourth is the *Journal of Industrial Ecology* (14 papers), in which the most frequent themes are the operational and strategic level, aligned to business education reflections, strategic niches approaches, low carbon city strategies, infrastructure and sustainable business models. The last two journals are *Waste Management* (8 papers) and *Bioresource Technology* (7 papers).

The sample core papers were identified from the citation and co-citation analysis, a quantitative technique applied to capture the impact and relevance of either an author or an article (Garfield and Merton, 1979). However, this evaluation should also consider the journal impact, in addition to counting the total citation or yearly average citation, because it "can change the position of one paper in the ranking of citations" (Carvalho et al., 2013), as shown in Equation (1).

$$\text{AIF} = \text{Yearly average citation} * (1 + \text{JCRIF}) \quad (1)$$

Equation (1) drives the further analysis for defining the core papers, using both yearly citation and journal relevance in the analysis. The impact factor and citations likely change over the years, however, since we used the average citation, the result obtained is less sensible to yearly variations then the one obtained by the use of total citations. Table 4 highlights the top articles considering the combined impact factor as proxy of relevance in the circular economy sample, emphasizing their research themes and journals.

Fig. 3 presents the performance of the core papers in a boxplot chart, emphasizing how outlier is each one of the top articles. The identified citation values represent papers from the sample whose article impact indexes are extreme outliers (asterisks), performing more than 7 citations. It evidences also the medium outliers (dots), of which citation values vary between 5 and 7, considering the impact factor. In view of the impact factor of the *Journal of Cleaner Production*, for instance, the paper from Mirabella et al. (2014), about food manufacturing waste, becomes the third in the total ranking instead of the eighth position regarding only the total citation. It is possible to observe also that most of the high impact factor papers are related to the Chinese perspective. An in-depth discussion of these papers is performed in the next sections.

### 4.2. Research streams

To understand the research collaboration on CE, the first network performed was the country co-authorship, performed with the software VosViewer version 1.6.1 (Eck and Waltman, 2010). Fig. 4 shows the relationship between countries.

The countries co-authorship network is composed of six clusters. The main cluster in terms of number of publications groups Australia, Austria, Italy, USA and England. The China, Japan and Canada cluster draws attention because of the high amount of Chinese studies. Finland, Germany, Denmark and Sweden form another grouping, and finally Belgium, Netherlands and Greece. The cluster grouping China, Japan and Canada highlights the great co-relationship between China and Japan, which have similar circular economy policies, focused on avoiding environmental damage and on natural resources conservation through integrated solutions for solid waste management (Su et al., 2013). It should be noted that only two papers of the total CE sample were effectively published in China, even though 40% of the authors are Chinese.

The CE approach in developing and developed countries should also be noted. The European Union has been developing a circular economy since 1995, by exploring and managing waste through treatment centers and recycling resources (Cucchiella et al., 2015).

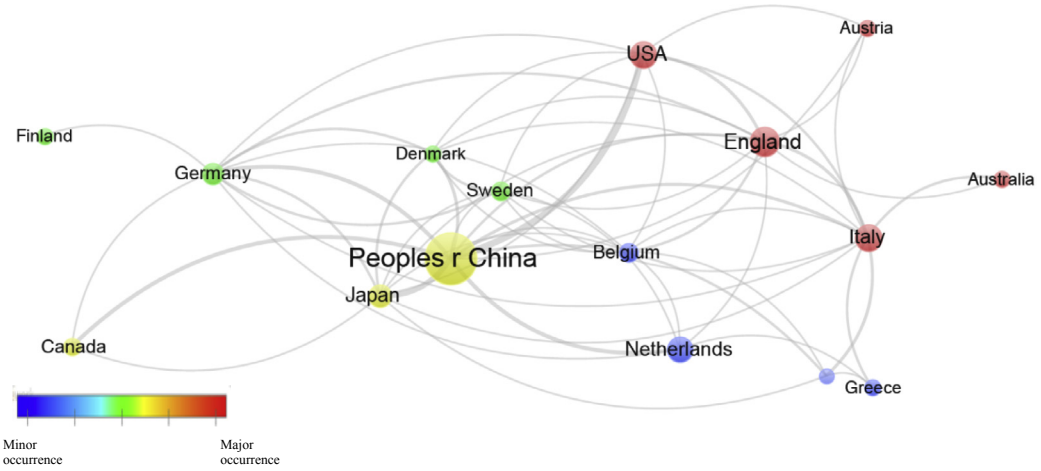


**Fig. 4.** Countries co-authorship for the circular economy sample. Note: This network was performed with threshold criteria of at least five articles co-authorship by VosViewer software using extracted data from the ISI and Scopus database. The size of the symbols corresponds to the number of publications citations and the color corresponds to the number of co-authorship occurrences in publications.

Here there is a more consolidated CE policy, in which resources conservation and "zero waste" is set as a goal (Manara and Zabaniotou, 2016). To achieve this, the co-authorship networks evidence the search for partnerships between European countries. On the other hand, the central government of China guaranteed in 2002 to stimulate the sustainable development of economy and society (Yuan et al., 2006). This has been led by technology innovation and capabilities creation at enterprise and mainly industrial zone level(Zhu et al., 2015).

The second analysis was performed using the co-citation network (Fig. 5) that illustrates the relationship between articles (Pilkington and Liston-Heyes, 1999; Pilkington and Meredith, 2009), clarifying the intellectual structure (Culnan and O'Reilly, 1990) and the research field connections (Bellis, 2009). The thicker the line linking two co-cited articles, the more frequent the co-citation is, indicating the relatedness of their research (Yu et al., 2014). The co-citation network brings together both the publications from the selected sample and also the references of this publications that do not belong to the sample, but that are always cited together in those publications (Pilkington and Meredith, 2009). This network presents the big picture of the research area, meaning that the more the publications are cited together, the more likely they are to delineate a "school of thought" (Culnan and O'Reilly, 1990). In this case, Fig. 5 represents the most relevant literature cited together in the circular economy research area.

Fig. 5 shows the co-cited articles from the circular economy sample that are clustered into four main groups: circular economy principles, symbiosis, ecoparks and supply issues. In this network, papers on circular economy principles mainly discuss concepts and case studies such as: Zhu et al. (2007); Li et al. (2010), while the implementation and benefits for countries and investors are concentrated in ecopark publications, such as the papers from Geng et al. (2009a, b, c); Shi et al. (2010); Yuan et al. (2006), Gibbs and Deutz (2007); Van Berkel et al. (2009). The need for circular economy in the supply area is another issue discussed in publications such as: Geng and Doberstein (2008); Geng, Zhu et al. (2009); Murphy and Gouldson (2000); Liu and Anbumozhi (2009) as well as business strategies to improve industrial economy and environmental performance by industrial symbiosis, such as Chertow (2000); Chertow and Lombardi (2005); Chertow (2007); Geng

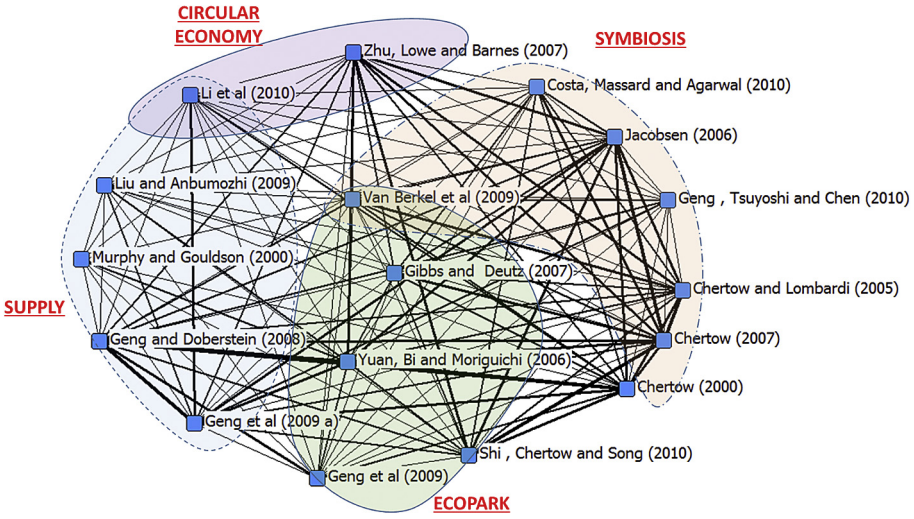


**Fig. 5.** Co-citation network for CE. Note: This network was created with Ucinet software using the metadata encoded by Sitkis software (filter criteria: at least seven citations per cited and citing reference) The strength of ties corresponds to the intensity of relationships.

et al. (2010).

### 4.3. Research topics and trends

In order to identify hot topics or compounds related to studies on circular economy, initially a scan was performed on the selected sample of 327 articles, using NVivo software (Bazeley and Jackson, 2013). This evaluation investigated the distribution and frequency of words on article titles, author keywords, abstracts and KeyWords Plus to obtain the most promising research topics and future trends. This led to a list of 24 recurrent topics or compounds, based on the software outputs (Fig. 6), meaning that "carbon emissions" is less frequently mentioned than the word "development".

To perform the "hot topics" analysis, a complementary analysis was undertaken, combining the recurring topics from Fig. 6, which provided the HB index (Hirsch, 2005). Using research by Banks (2006), index M from Fig. 6 was calculated in this paper as a linear mathematical relationship between h-b and the number of years n (n = 11 years), elapsed since the first publication (in this case, 2006), including the topic or compound, Equation (2).

$$HB \sim M^{*}n \quad (2)$$

The criteria for the interpretation of the M index are presented in Fig. 6, according to Banks' criteria (2006). In this sample, the "carbon emissions" issue is not yet a hot topic within circular economy; however, themes of "supply" and "supply chain" are at the lower end of being considered hot topics. This may represent a gap in research to be explored (circular economy and the supply chain). Words such as "industrial", "China", "products" already appear as known issues within circular economy.

To complement the overview on the selected sample (327 papers), the circular economy keywords network is presented in Fig. 7. These words were categorized into 4 main groups: (1) strategic variable, that corresponds to the main drive to circular economy (sustainable development); (2) operational variables, corresponding to the path that can be used to reach circular economy (design, model, system(s), management, waste management, performance and challenges), (3) inputs that are the independent variables within the circular economy research theme (Chine, industry, environment, energy, ecology) and (4) outputs, that are the result of the circular economy implementation (recycling, symbiosis, reuse, industrial symbiosis, sustainability, industrial ecology, waste, emission, eco-efficiency).

The strength of the ties connecting the nodes illustrates the intensity of the relationships of the keywords mentioned together in the sample (Carvalho et al., 2013). The filter criteria for this diagram were set at a minimum of ten occurrences for each keyword. The main connections revealed are the ones between CE and management (or waste management), CE and sustainable development, CE and industrial symbiosis and ecology. There is also an outstanding connection between CE and China, owing to the number of publications about Chinese cases, mostly related to Industrial Ecology and Eco-Industrial Parks. Further support for understanding these relationships was obtained from the content analysis.

### 4.4. Circular economy definitions analysis

Since circular economy is an emerging topic and the term still lacks a structured definition, a semantic analysis was performed in order to gain a better understanding of its meaning within the related literature. This method involves an analysis of syntactic structures and textual context in a selected sample (Wang and Tsai, 2009). For this procedure, the authors searched for CE definitions in the sample of papers, in which 35 definitions were selected (Appendix A). A detailed analysis of the definitions was realized with the support of the software Tropes, and a more comprehensive "CE sample-based" definition was shaped. The results are detailed in Table 5 and Fig. 9.

The words most closely connected (Table 5) are "circular economy" and "resource", and "resource" and "productivity", evidencing the eco-efficiency theme in the papers. Other frequent word connections are "waste", "energy" and "equipment". Fig. 8 presents the connections (actant/acted straightness) between words from the definitions of circular economy.

Regarding the software analysis results (Fig. 8), the outlined area in the chart represents the location of the term "supply chain" in the CE context. Based on the Tropes statistics report and the whole research process (Table 5 and Fig. 8), one important output is that the link between "supply chain" and "circular economy" is weakly established in the studied definitions, and this needs further analysis.

In the research stream analysis, based on the bibliometrics, it was possible to identify a cluster related to "supply", but it does not stood out in the semantic analysis. Thus, despite some studies exploring opportunities in circular supply chains for renewable chemical feedstock (Tsolakis et al., 2016); network reconfiguration (Srai and Kumar, 2017) and sustainable supply chain management towards a circular economy (Genovese and Figueroa, 2017), these

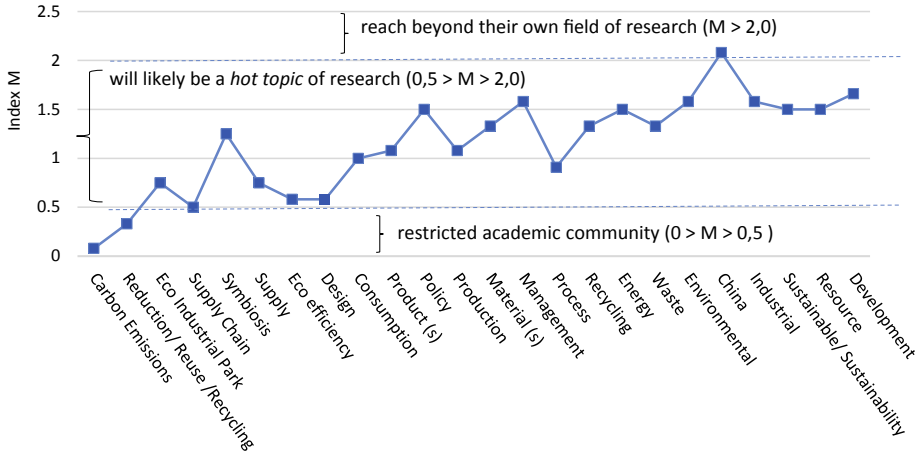


**Fig. 6.** Hot topics in percentage from the CE sample.

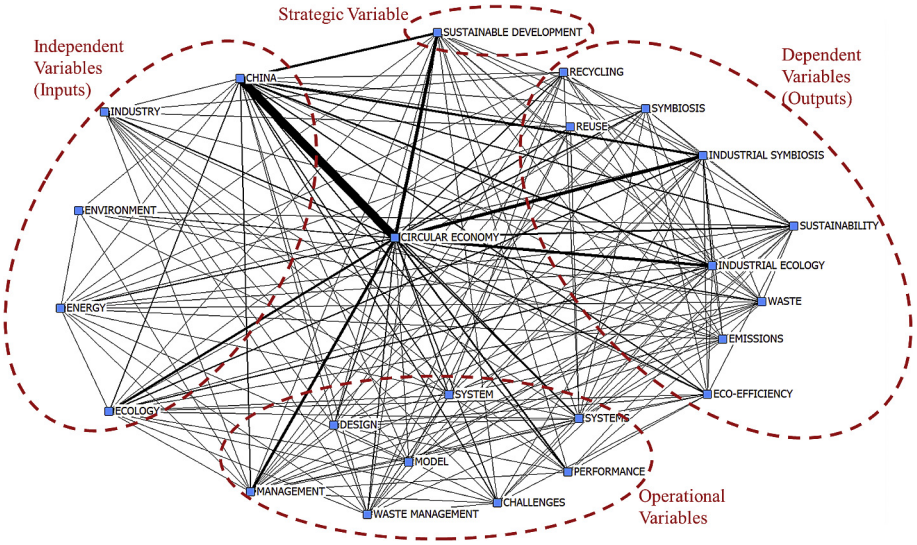


**Fig. 7.** Keywords network from the CE sample. Note: This network was performed by Ucinet software using extracted data from Sitkis software. The strength of ties correspond to the intensity of relationships (a minimum of ten occurrences). On the left the main inputs (independent variables), on the right the main outputs (dependent variables), in the bottom the operational variables, in the top the strategic variables.

**Table 5**
Tropes statistics report.

| Main themes[a] | Frequency | Main themes[a] | Frequency | Relations (Tightly connected[a]) | Frequency |
|---|---|---|---|---|---|
| circular economy | 39 | model | 4 | (circular economy > resource) | 7 |
| resource | 27 | productivity | 4 | (resource > productivity) | 6 |
| equipment | 16 | consumption | 4 | (resource > eco efficiency) | 4 |
| economy | 13 | part | 3 | (waste > resource) | 4 |
| product | 12 | life | 3 | (equipment > energy) | 4 |
| development | 7 | closedloop | 3 | (circular economy > equipment) | 4 |
| way | 7 | cycle | 3 | (productivity > eco efficiency) | 4 |
| waste | 7 | sustainable development | 3 | (circular economy > sustainable development) | 3 |
| value | 7 | market | 3 | (circular economy > closed loop) | 3 |
| environment | 6 | supply chain | 3 | (product > design) | 3 |
| energy | 6 | improvement | 3 | (circular economy > strategy) | 3 |
| use | 6 | procedure | 3 | (strategy > resource) | 3 |
| management | 6 | concept | 3 | (use > resource) | 3 |
| strategy | 5 | production | 3 | (closedloop > s) | 3 |
| industry | 5 | scarcity | 3 | (resource > improvement) | 3 |
| china | 4 | aim | 3 | (way > resource) | 3 |
| design | 4 | | | (development > resource) | 3 |
| system | 4 | | | (circular economy > development) | 3 |
| eco efficiency | 4 | | | (resource > scarcity) | 3 |

[a] At least three times

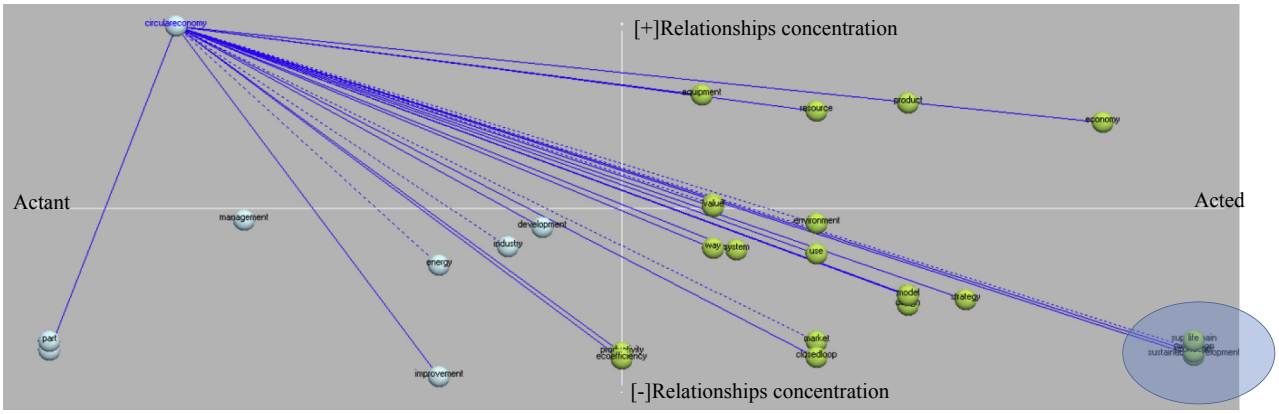


**Fig. 8.** Example of an actor's graph linked to the definitions of circular economy (origin of all conexions). Note: The X axis (horizontal) shows the actant/acted ratio (from left to right). The Y axis (vertical) shows the relationships concentration for each reference displayed (strong at the top of the graph, weak at the bottom). The lines show the relationships between the references.

are not yet the core subject in circular economy definitions.

Some authors argue that circular economy as an alternative model to traditional linear economy (Gregson et al., 2015), needs to be treated in a holistic manner (Jiao and Boons, 2014). As a synthesis of the sample definitions analyzed established that the most recurrent phrases lead to CE being: a new strategy (Su et al., 2013) or a path (Zhang et al., 2009) for promoting sustainable development, reducing environmental harm and facing the challenge of resource scarcity (Yuan et al., 2008). It is important to note that social aspects are neglected as part of the sustainable development goals in most definitions; whereas the link between economic and environmental issues is stressed in several papers. CE aims to improve efficiency in materials and energy (Hu et al., 2011; Geng and Doberstein, 2008), through a minimized input of virgin materials and reduced outputs of waste (Haas et al., 2015), and closed loops of reuse and recycle (Peters et al., 2007; Jiao and Boons, 2014). Some authors also mention that the change to a circular economy also demands changes in product design, manufacturing and supply chain management approaches (Smol et al., 2015; Wei et al., 2014).

Based on the results of the analysis, a definition is proposed: *CE is a strategy that emerges to oppose the traditional open-ended system, aiming to face the challenge of resource scarcity and waste disposal in a win-win approach with economic and value perspective*. The circular aspect of this concept is core, based on the understanding of the several possible biological and technical loops, which differs from other sustainable development approaches. Since circular economy is based on principles such as lifecycle extension, sharing, reuse, recycling, remanufacturing and refurbishing, its feasible implementation depends on rethinking operations management, particularly products and services lifecycles (beginning of life – BOL, middle of life – MOL, and end of life – EOL), manufacturing processes and supply chain management activities.

### 4.5. Content analysis

The overall results of the content analysis based on the codes tree is presented in Fig. 9. The selection criteria to perform this step was to address the supply chain perspective, since this field presents one of the weakest links identified by the semantic analysis. It should be also noted that to operationalize properly the next steps towards circular economy, the whole supply chain needs to adapt (Srai and Kumar, 2017; Tsolakis et al., 2016). Thus, the most relevant papers linking supply chain and circular economy were selected gathering a core sample of 39 papers.

It can be noted that most papers discuss closing the loop (63%) and externalities (35%). Regarding the research methods applied, the case study (46%) is the most often used. Still, just a few papers discuss CE from a triple bottom line perspective (19%).

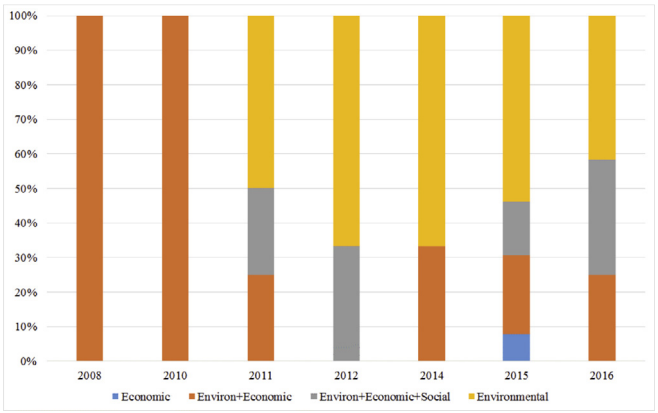


**Fig. 10.** TBL approach yearly evolution.

The content analysis applying the triple bottom line codes (see Fig. 10), allows the evolution of the TBL (social, environmental and economic) pillars over time. Environmental and economic issues are the most frequent, while concern with social issues emerges in papers, suggesting integrated policies and regulation implementation impact directly on people's wellbeing in industrial areas such as the paper of Boons et al. (2011) and Geng et al., (2009a). Regarding these social aspects, to increase circular economy effectiveness, it is essential to consider "what collaborative efforts or policy intervention would be relevant"(Diener and Tillman, 2016).

The recent British Standard Framework to CE (BS 8001:2017) is one example of the many efforts towards scaling up the circular economy implementation. Many companies, universities and governmental agencies were involved in the development of this practical implementation guide based in six main principles: systems thinking; innovation; stewardship; collaboration; value optimization and transparency (BS, 2017), concentrating on the move from the old-fashioned and polluting linear economy to the innovative and sustainable CE.

Besides that, Table 6 presents the most relevant papers that explicitly mention the importance of policies and regulation to leverage the CE implementation.

Positives impacts can also be reached by "developing the domestic secondary supply of REE (Rare Earth Element)", because it can provide societal benefits by supporting regional and national goals towards circular economies (Machacek et al., 2015). However, unsustainable production and consumption, especially in industrialized countries, are pointed as great causes of environmental damage (Veleva et al., 2001).

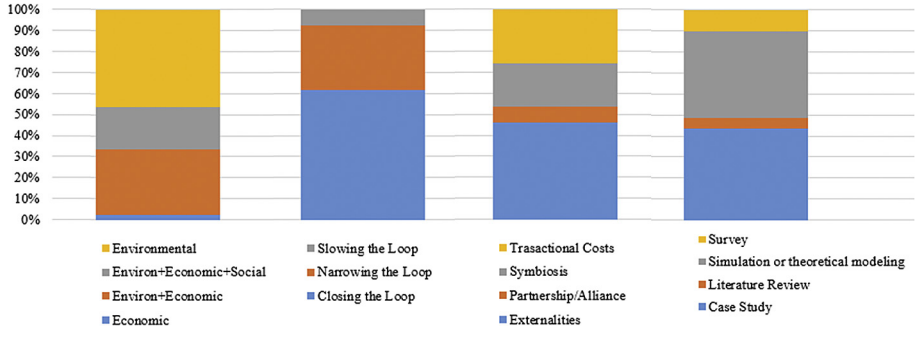


**Fig. 9.** Summary of the content analysis.

**Table 6**
Most relevant papers mentioning the impact of policies and regulations towards the implementation of CE.

| Authors | Times Cited | Subject |
|---|---|---|
| Peters et al., 2007 | 263 | The paper discusses and analyzes the growth of energy consumption and CO2 emissions in China, as well as the application of public policy developments to try to reduce this problem. |
| Geng and Doberstein, 2008, p. 1 | 85 | As explained by the authors: "The paper describes current measures being implemented in China for the long-term promotion of a circular economy, including the formulation of objectives, legislation, policies and measures, so that the country can 'leapfrog' its way from environmentally damaging development to a more sustainable path. |
| Geng et al., 2012 | 77 | The article discusses China's rapid economic growth and its negative effects on the environment. The authors wrote that CE has been chosen as a national policy for sustainable development, to implement the national laws and regulations have been enacted to facilitate the implementation. |
| Su et al., 2013 | 69 | The article discusses CE in China and how this legalization, accepted since 2002, helps to improve the efficient use of raw materials and preserving the environment. |
| Zhang et al., 2010 | 57 | The rapid development of eco parks in china and the involvement of government agencies are discussed in this article. |
| Zhu et al., 2011a, b | 57 | China's supply chain has been under regulatory pressure to implement sustainable practices. |
| Zhang et al., 2011 | 51 | The large number of vehicles of china and the lack of material to continue the production, raise new concern for the Chinese government. The automotive remanufacturing industry in China is only at the preliminary stage, and encounters some barriers, including policies and regulations. |
| Dong et al., 2013 | 44 | The importance and benefits of industrial symbiosis (IS) formation in China are addressed in this paper. Among other points, legislative framework and support policy, are needed to support the ever-improving IS promotion in China's iron/steel industry. |
| Geng et al., 2010 | 41 | The article discusses the main initiatives for cleaner production in China and comments that regional governments have played a leading role in promoting it. |
| Li et al., 2010 | 39 | Policies and programs of Chinese government related to energy conservation were introduced in combination with China's circular economy structure, to solve environmental problems in China. |

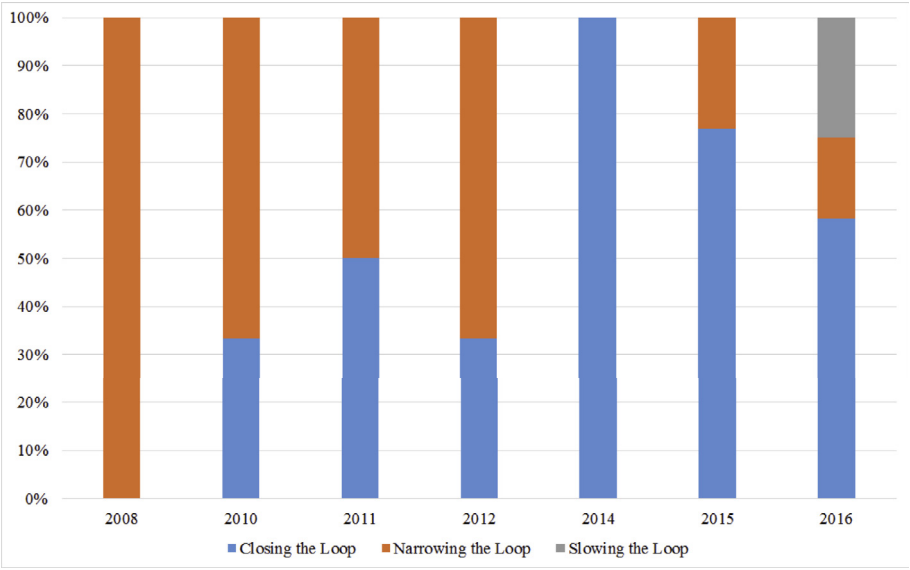


**Fig. 11.** Approach evolution over the years.

The CE analysis on the efficiency of supply chain, narrowing the loop (Fig. 11) shows that it was initially an important subject related in 12 papers such as: Yuan et al. (2008); Zhu et al. (2010); Zhu et al., (2011a); Zhu et al. (2011a, b). However, closing the loop began to grow as a goal and 24 papers of this sample present this approach, i.e. Cucchiella et al. (2015); Pan et al. (2014); Tu et al., 2011. Currently, the extended lifecycle is featured in circular economy

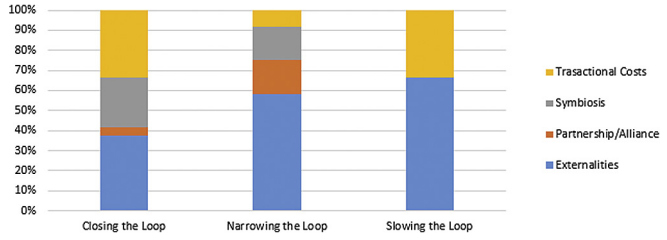


**Fig. 12.** Main themes according to the CE approach.

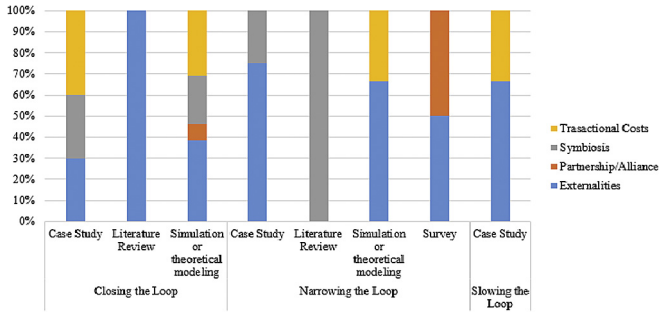


**Fig. 13.** Distribution of research methods according to main issues and CE approach.

discussion, in just three papers of this sample (Dalhammar, 2016; Pollard et al., 2016; van Weelden et al., 2016). Figs. 11–13 show the summary of this analysis.

The conceptual analysis is composed of simulation and theoretical modeling and literature review, addressing corporate sustainability (Bai et al., 2015) and critical materials for product design (Peck et al., 2015). Only a few surveys were identified in the sample, all of them from the same main author i.e.Zhu et al. (2011a, b); Zhu et al., (2011a); Zhu et al. (2010); Zhu et al. (2012) and only two of them dealing with partnership issues, practices in CE and environmental supply chain cooperation, and performance results. Most papers used quantitative approaches, but a few used qualitative approaches.

Within the eco-supply approach, "green supply chain management has emerged as an important organizational philosophy to reduce environmental risks" (Diabat and Govindan, 2011). Note that the most cited paper of this sample is a survey about green supply chain evaluation from an ecological modernization perspective paper of Zhu et al. (2011a), which enables an innovative systems solution during the supply chain transition path (Potting et al., 2016).

As expected, the symbiosis code is relevant, corresponding most to closing and narrowing the loop (Fig. 12). The most relevant papers in terms of symbiosis classification are the theoretical modeling on the organizational complexity of ecoparks (Chertow and Ehrenfeld, 2012), a qualitative case study about the experiences of Tianjin (Shi et al., 2010) and a framework about the dynamics of industrial symbiosis based on a literature review (Boons et al., 2011). They express and prove in different ways that "turning waste into a resource is a way to increase resource use efficiency and close the material loop of a circular economy" (Jimnez-Rivero and Garcia-Navarro, 2017).

Regarding the partnership and alliance, these terms are mostly in case studies papers (Fig. 13), contextualizing pilot practices (Zhang et al., 2010), process integration (Yu et al., 2014), evolution of symbiosis approaches (Yu et al., 2015b) and the effect of policy instruments (Yu et al., 2015a). There is only one paper with a theoretical quantitative modeling approach on the perspectives of the development of ecoparks in China, based on past experiences of senior officials from 51 Chinese industrial parks (Zhu et al., 2014). The most cited paper of this sample is a Tianjin economic-technological development area in China (Shi et al., 2010), a qualitative case study focusing on industrial symbiosis. The symbiosis subject is therefore, closely related to the ecopark concept, followed by partnership issues. Regarding partnership, it should be noted that there is a lack of investigation on how this paradigm can be enabled through inter-organizational cooperation among different business companies (Ruggieri et al., 2016).

Another interesting point is that transactional costs appear in a quantitative way only in the context of narrowing the loop (eco-efficiency) i.e.Liu et al. (2015); Yong, Geng et al. (2014); Yong, Geng et al. (2009a). Related to that, to effectively accomplish the goal of circular economy to a great extent, according to Ayres et al. (2013), "major investments in energy efficiency and renewable energy technologies in the near and medium term" are required. The CE solution must encompass "long-run (20–30 years) investors (pension funds, insurance companies) and probably take the form of securitized, resource-based bonds" (Ayres et al., 2013).

Chinese case studies are a constant in this sample, followed by theoretical modeling, mainly in using the closing-loop approach. Table 7 presents the most relevant case studies from the sample.

For the slowing loop approach, there is still a gap, perhaps because extending a product's life strongly depends on closer implementation by the consumer as well, which may also mean a huge change on cultural consumption patterns (Pollard et al., 2016; Van Weelden et al., 2016).

Slowing the loop could also be reached by "using products more intensively; for longer; light weighting products and increasing reuse, at the product and at the component levels" (Pauliuk et al., 2017). As mentioned previously, "legislation, like a business strategy, can be driven by a different perspective of value and alignment with the goals of a circular economy agenda" which encompasses another fundamental pillar to CE deployment (Machacek et al., 2015).

## 5. Discussion

Although some previous literature reviews on CE were identified during the analysis process (Appendix B), none have so significant a sample and applied multi-methods analysis. Moreover, none explore together the loops approach, the industrial ecology topics and the TBL perspectives, or specifically address circular economy in the context of material flow and the macro issues of circular economy. The main themes addressed in previous reviews are the industrial symbiosis as unit of analysis and the deployment of specific technical issues.

This systematic literature review confirms, according to Ezzat (2016), that some of the circular economy model dimensions are absent, including "the legislative, institutional and cultural issues". Regarding their influence in social discussion, these missing dimensions are considered to present major challenges to transitioning towards a circular economy model; instead, there remains support for a linear economy (Ezzat, 2016).

Three main clusters within the CE field were identified: symbiosis, ecoparks and supply chain. The overview given by this research, at this point, provides some main results that should be emphasized. General publications on circular economy come mostly from China-related cases, since the mandatory CE regulation was enforced in 2009 (Jiao and Boons, 2014; Yu et al., 2014). These publications are concerning particularly to symbiosis and ecoparks clusters. Nevertheless, the growing number of publications, as evidenced by the yearly evolution of publications, show different pathways to the circular economy development indicating new trends.

To amplify the insights on the supply cluster, a specific additional research filter was performed, based on the main CE sample. The evidences show that the bridge between supply chain and circular economy despite emergent shows new trends. Although the supply chain research field is well established and the CE approach is relatively new, it should be noted that the theoretical bridge between both researches bodies need to be enhanced.

Although some advances were performed by exploring opportunities in circular supply chains to nurture the transition towards a circular economy (Genovese and Figueroa, 2017) and to foster the network reconfiguration (Srai and Kumar, 2017), further research efforts are needed. The perceptions of the sample showed that some linkage are lacking, mainly among industrial sectors' needs and the collaboration between internal or external partners with the supply chain members to properly implement environmental practices (Zhu et al., 2010). This is a broader perspective on what remains a gap to be more intensively addressed, rather than tools, best practices to circular economy theory and its supply deployments.

Regarding the supply cluster, the complexity of the CE business context related to the organizational interchange of by-products and waste outputs was slightly mentioned as a background context, the core of the sample focused on the biochemical part of the loop. As already mentioned by Satchatippavarn et al. (2016), it was evidenced that most studies frequently focus on the set of goals needed to achieve a sustainable system, by connecting the whole

**Table 7**
Most relevant papers about case studies.

| Authors | Times Cited | Subject |
|---|---|---|
| Shi et al. (2010) | 111 | A case study of the Tianjin Economic-Technological Development Area, assessing the environmental benefits of the key symbiotic exchanges in TEDA. |
| Geng et al. (2010) | 58 | The paper provides insight into the environmental performance and sustainability of an industrial park. |
| Xi et al. (2011) | 54 | This paper shows how a clear inventory analysis on GHG emissions at city level can help to identify the major industries and societal sectors for reduction efforts so as to facilitate low-carbon policy-making. |
| Park et al. (2010) | 47 | This paper investigates the challenges and opportunities of how firms and organizations can and will be able to strike a better balance between economic growth and environmental stewardship in the context of China's emerging 'circular economy' policy. |
| Yang and Feng (2008) | 42 | This study expounds on its whole transition course to a circular complex in the past decade, in which four factors are essential to making this symbiosis achievable: rational production structures; raw materials advantages; technical supports and correct diversification. |
| Geng et al. (2010) | 41 | This paper reflects such a perspective through a case study of Liaoning province. |
| Liu and Anbumozhi (2009) | 40 | This study creates a better understanding of public awareness and performance in the promotion of a Circular Economy (CE) in Tianjin, China. |
| Mo et al.(2009) | 34 | This paper characterizes the current recyclable resource recycling system by a detailed field survey carried Out from 2006 to 2008 in Suzhou city. |
| Chen et al., 2012 | 27 | By analyzing 88 sample recycling projects in 23 eco-towns in Japan, this article focuses on the factors of project scale, recycling boundary, and types of waste in relationship to environmental benefits and operational performance. |
| Dong et al. (2013) | 24 | This research shed light on how industrial symbiosis contributes to city's low-carbon development. |

supply chain, however, the economic factor overlies any other aspect. About possible streams for innovation towards more sustainable supply chains (Garetti and Taisch, 2012; Potting et al., 2016), since it is a move from the *status quo* towards closing the loop (Bocken et al., 2016), the evidences presented that: because of the high complexity of circular supply chain operations (Barber et al., 2012), new business approaches must be stimulated (Bocken et al., 2014) in order to accomplish a broader mindset of sustainability imperatives (Abdallah et al., 2012).

Another trend that stood out in recent years is the link between circular economy and business model literature, which shows new research opportunities, by discussing value propositions based on offerings (products, services and results) and also on exploring material closed-loop for profit (Evans et al., 2017). A few papers dealing with the question of dematerialization by the product and service approach were identified, only two bridge the question to the circular economy context, presenting another gap for future research (Tukker, 2015; Vasantha et al., 2015).

Most of the CE approaches are incremental innovations, indicating minor improvements or small adjustments to existing technologies or processes (Abernathy and Utterback, 1978). However, “the move to a circular economy model is an example of a radical change” (Bocken and Short, 2016, p.312) and to perform a radical change of patterns, major technical breakthroughs may have to be even more emphasized to reach new ways of thinking and doing business.

Another core aspect to the dissemination of a CE strategy through the whole supply chain, transforming it into a circular one, is the necessity of a trained and informed public (Yuan et al., 2008), as well as a systematic regulation and policy system, with better interactions among governmental bodies, policy makers, communities and manufacturing industries (Lieder and Rashid, 2016). Probably, because CE has evolved from waste generation research, resource use and environmental impacts assessments fields, it has been realized that the economic aspects for manufacturing are intensively being pursued, since they are not yet quite clarified. The advantages for industry must be made more explicit in order to create successful CE implementation, based also on economical supports and pollution regulations from government (Pan et al., 2015).

Although the “European Commission adopted a new Circular Economy Package, including revised legislative proposals on waste to stimulate Europe's transition towards a circular economy; to foster sustainable economic growth and generate new jobs” (Riisgaard et al., 2016), more intensive consequential knowledge dissemination must be performed, probably through education.

Some fundamental challenges to improving the CE transition are related to the fragility of the mechanisms of its economic viability (Genovese and Figueroa, 2017) by utilizing circular rather than linear supply chains; the main strategy is to re-target production processes following a pattern of enhanced sustainability features (Yuan et al., 2006). This means that to “achieve sustainable performance, sustainable operations need triple-bottom-line (TBL) thinking that integrates economic, environmental and social issues into its business processes”. That means it should include the reducing of materials in designing, manufacturing, transporting, recycling, reusing and remanufacturing of products. (Wu et al., 2017; Kleindorfer et al., 2005).

Therefore, if the boundaries of environmental sustainability are to be pushed, especially in energy and material intensive industries, the understanding of economic and environmental cascade implications, by intensive empirical and practical studies reporting lessons learnt, are fundamental to sustainable supply chain strategies focusing in circular economy principles (Nasir et al., 2017).

## 6. Conclusion

This study contributes to narrow the gap in the literature in three ways. First, it presents a definition of CE based on the semantic-sample, helping to build a consensus around the CE concept. Second, the paper presents a panorama of CE based on a large sample, outlining the yearly evolution, core authors, topics, and journals. Third, based on an in-depth content analysis, the paper presents main trends, content from the main research partnerships between countries and research gaps.

Despite the growing research into the field of CE, it was observed still to be in an exploratory phase, with most of articles adopting exploratory research methods, particularly case studies, and lacking a confirmatory approach and empirical validation. Most of the constructs involved in the CE literature still need to be further refined and a more homogeny nomenclature should be applied.

As implications for practice, we highlight the increasing interest about the topic. From the perspective of a policy maker, the eco-parks literature presents successful examples, exploring how externalities, transaction costs and symbiosis can contribute towards a CE. For companies, new business models are explored, with different kinds of loop approaches, particularly the sharing economy, and this can help organizations have insights on new

opportunities to move towards a CE.

This research has limitations related to the use of search engines and the methodological choices concerning the search string, filters and databases selected. The content analysis, despite being performed by a group of four researchers, may generate an interpretation bias. However, the systematic multi-method approach applied (semantic, bibliometric, network analysis and content analysis) helps to mitigate these limitations.

This exploratory work highlights that circularity brings new inspiration and challenges for future research. The study points out the lack of more confirmatory research approaches, applying a TBL perspective, since the focus until now remains from economic-environment perspectives. The CE literature on loop approaches and industrial ecology are not well linked and the theoretical foundations of these two research streams need to be more aligned.

## Acknowledgements

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## Appendix A. List of Circular Economy definitions in the sample

| Reference | Definition |
|---|---|
| Birat (2015) | CE is a contemporary and popular concept that describes how materials and resources should be handled in the future |
| "Circular Economy in Australia," (2016) | CE is an alternative model that anticipates and designs for biological and technical 'nutrients' to be continuously re-used at the same quality, dramatically reducing our dependency on sourcing new materials |
| "COARA - Commercial Asset Recycling,"(2016) | CE is driven by the desire to use the value in products we already have that might previously have been thought of as waste. But a transition from the traditional linear economy where we use raw materials to make a product, use it and then discard that product once it has ceased to function, or simply becomes out-dated, requires changes in product design, the manufacturing process, supply chain, consumer perception and attitude. |
| MacArthur (2013) | CE is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles |
| Geng and Doberstein (2008) | CE has the potential to overcome current environmental and resource management problems while achieving improvements in resource productivity and eco-efficiency<br>CE encourages the creation of a conservation oriented society, seeking to reduce both total consumption and waste production<br>CE is normally understood to mean the realization of a closed loop of materials flow in the economic system. Successful implementation of the circular economy concept is one way that China can "leapfrog" past the environmental damages that are typically seen as economies industrialize |
| Gregson et al. (2015) | CE has emerged recently as a policy goal in the context of rising resource prices and climate change. The aim is to move away from the linear economic model, summarized as 'take– make– dispose' with raw materials in at one end and externalized wastes at the other<br>CE appears to decouple economic growth from increasing resource use as well as promoting waste reduction or minimization<br>CE will mean choosing specific configurations of materiality and market, with differing moral values, and not just physical or technical mechanisms, to rekindle value in recalcitrant waste materials – in ways that compete with global resource and recycling markets |
| Haas et al. (2015) | CE is a simple, but convincing, strategy, which aims at reducing both input of virgin materials and output of wastes by closing economic and ecological loops of resource flows |
| Hepler (2015) | A successor to the practice of old school "reduce, reuse, recycle" mantras, these examples of unconventional material re-purposing help illustrate the much-hyped circular economy — a more ambitious, and more marketing-friendly, rethinking of how product materials and packaging can be cycled back into supply chains |
| House of Commons/Environmental Audit Committee (2014) | CE maximises the sustainable use and value of resources, eliminating waste and benefiting both the economy and the environment. It offers an alternative to the predominant current approach where resources are used for one purpose and then discarded<br>The idea is not new, and is associated with a range of concepts such as 'cradle to cradle' design and 'industrial ecology', which draw inspiration from biological cycles and emphasise the importance of optimising the use of resources in a system over time. A circular economy includes a range of processes, or 'cycles', in which resources are repeatedly used and their value maintained wherever possible |
| Hu et al. (2011) | CE focuses on resource-productivity and eco-efficiency improvement in a comprehensive way, especially on the industrial structure optimization of new technology development and application, equipment renewal and management renovation<br>CE focuses on resource-productivity and eco-efficiency improvement in a comprehensive way, especially on the industrial structure optimization of new technology development and application, equipment renewal and management renovation |
| Jiao and Boons, 2014 | CE was defined as a holistic concept covering the activities of 'reduce, reuse, and recycle' in the process of production, circulation, and consumption |
| Li et al. (2010) | CE aims at closed-loop material and energy systems in all sectors of industry in order to reduce the use of natural resources and the environmental impact |
| Lieder and Rashid, 2016 | CE is to an increasing extent treated as a solution to series of challenges such as waste generation, resource scarcity and sustaining economic benefits |
| Peters et al. (2007) | The central idea is to close material loops, reduce inputs, and reuse or recycle products and waste to achieve a higher quality of life through increased resource efficiency |
| Smol et al. (2015) | Transition to a more circular economy requires changes throughout value chains, from product design to new business and market models, from new ways of turning waste into a resource to new modes of consumer behaviour |
| Su et al. (2013) | CE is a sustainable development strategy aiming to improve the efficiency of materials and energy use<br>CE is a sustainable development strategy proposed by the central government of China, aiming to improve the efficiency of materials and energy use<br>CE can be defined as an economy type with a closed-loop of material flows, which is opposite to the traditional open-ended economy<br>CE has been first raised by two Bristh environmental economists Pearce and Turner (1990). In Economics of Natural Resources and the Environment, they pointed out that a traditional open-ended economy was developed with no built-in tendency to recycle, which was reflected by treating the environment as a waste reservoir |
| Tukker (2015) | CE is based on the "win-win" philosophy that a prosper economy and healthy environment can be co-existed |

(*continued*)

| Reference | Definition |
|---|---|
| "The Waste and Resources Action Programme" (2004) | CE is is an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life |
| Wei et al. (2014) | CE is a model of economic development to maximize the use of resources and protect the environment. Guided by the theory of recycled economy, green supply chain management, as a new notion of management, plays a more and more important role in the development of manufacturing industry in Guangxi |
| Wen et al. (2007) | CE and eco-industry are effective ways to solve sustainable development problems on resources, environment and economy |
| Yuan et al. (2008) | CE was promoted in China as a new development strategy to alleviate the shortage of resource supply by improving the resource productivity and the eco-efficiency of production and consumption<br>CE is a political strategy aiming to alleviate the resource scarcity and reduce pollution, and so it is essential to find effective ways to educate or train people so that they can implement the concept into their everyday work and life<br>In an ideal CE system, all the materials and energy are effectively utilized and therefore the environmental impacts of development on the ecosystem are reduced to the minimum |
| Zhang et al. (2009) | CE could be considered a path to sustainable development where industrial symbiosis in eco-industrial parks (EIPs) constitutes an important segment of this strategy |
| Zhu et al. (2010) | Due to resource scarcity and environmental degradation, a new development concept emphasizing environmental concerns, called the circular economy |
| Zhu et al. (2011a) | CE promotes continuous economic development without generation of significant environmental and resource challenges. It advocates that economic systems can and should operate according to the materials and energy cycling principles that sustain natural systems. CE also emphasizes the recycling of essential materials and energy as well as the capacity for one entity's wastes to be used as a resource by another entity through self-organization capacities |
| Nguyen et al. (2014) | CE aims to eradicate waste—not just from manufacturing processes, as lean management aspires to do, but systematically, throughout the life cycles and uses of products and their components. Indeed, tight component and product cycles of use and reuse, aided by product design, help define the concept of a circular economy and distinguish it from the linear take–make–dispose economy, which wastes large amounts of embedded materials, energy, and labor. |

## Appendix B. Previous CE Reviews

| Authors | Year | Title | Journals | Method | Time Range | Articles |
|---|---|---|---|---|---|---|
| Lieder and Rashid, 2016 | 2016 | Towards circular economy implementation: a comprehensive review in context of manufacturing industry | Journal of Cleaner Production | Database search; systematic literature review | 1950–2015 | 215 |
| Supino et al. (2016) | 2016 | Sustainability in the EU cement industry: the Italian and German experiences | Journal of Cleaner Production | Database search; review | 2000–2013 | |
| Pellis et al. (2016) | 2016 | The Closure of the Cycle: Enzymatic Synthesis and Functionalization of Bio-Based Polyesters | Trends In Biotechnology | Bio-based polyester review | xx-2016 | |
| Lewandowski (2016) | 2016 | Designing the Business Models for Circular Economy-Towards the Conceptual Framework | Sustainability | Database search; literature review | until 2015 | 94 |
| Ampelli et al. (2015) | 2015 | CO2 utilization: an enabling element to move to a resource- and energy-efficient chemical and fuel production | Philosophical Transactions of The Royal Society A-Mathematical Physical And Engineering Sciences | Review | 2000–2050 | |
| Cucchiella et al. (2015) | 2015 | Recycling of WEEEs: An economic assessment of present and future e-waste streams | Renewable & Sustainable Energy Reviews | Database search; review | 1995–2015 | |
| Tukker (2015) | 2015 | Product services for a resource-efficient and circular economy - a review | Journal of Cleaner Production | Database search; literature review | 2003–2013 | 278 |
| Dodson et al. (2015) | 2015 | Bio-derived materials as a green route for precious & critical metal recovery and re-use | Green Chemistry | Review | 1998–2013 | 218 |
| Lu et al. (2015) | 2015 | An overview of e-waste management in China | Journal of Material Cycles And Waste Management | Database search; review | 2015 | |
| Pan et al. (2015) | 2015 | Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review | Journal of Cleaner Production | successful lessons on WTE supply chains | xx-2015 | |
| Walls and Paquin (2015) | 2015 | Organizational Perspectives of Industrial Symbiosis: A Review and Synthesis | Organization & Environment | Database search; systematic literature review | 1995–2015 | 121 |
| Vasantha et al. (2015) | 2015 | Advances in Designing Product-Service Systems | Journal of The Indian Institute of Science | Database search; literature review | 2001–2015 | 20 |
| Mirabella et al. (2014) | 2014 | Current options for the valorization of food manufacturing waste: a review | Journal of Cleaner Production | | 2000–2012 | 111 |
| Xue et al. (2014) | 2014 | A review on China's pollutant emissions reduction assessment | Ecological Indicators | Database search; literature review | 2009–2013 | |
| Jiao and Boons, 2014 | 2014 | Toward a research agenda for policy intervention and facilitation to enhance industrial symbiosis based on a comprehensive literature review | Journal of Cleaner Production | Database search; literature review | 2001–2015 | 37 |
| Manomaivibool and Hong (2014) | 2014 | Two decades, three WEEE systems: How far did EPR evolve in Korea's resource circulation policy? | Resources Conservation And Recycling | Database search; review | 2002–2012 | |
| Jones et al. (2013) | 2013 | Enhanced Landfill Mining in view of multiple resource recovery: a critical review | Journal of Cleaner Production | Database search; literature review | 1991–2011 | 12 |

(*continued on next page*)

(*continued*)

| Authors | Year | Title | Journals | Method | Time Range | Articles |
|---|---|---|---|---|---|---|
| Su et al. (2013) | 2013 | A review of the circular economy in China: moving from rhetoric to implementation | Journal of Cleaner Production | Database search; review | 2002–2011 | – |
| Feng et al. (2012) | 2012 | Household biogas development in rural China: On policy support and other macro sustainable conditions | Renewable & Sustainable Energy Reviews | Database search; Policy review | 2002–2011 | |
| Sakai et al. (2011) | 2011 | International comparative study of 3R and waste management policy developments | Journal of Material Cycles And Waste Management | review about 3R | xx- 2011 | |
| Chang et al. (2011) | 2011 | Comprehensive utilizations of biogas in Inner Mongolia, China | Renewable & Sustainable Energy Reviews | Database search; literature review | end 2009 | |
| Li and Yu (2011) | 2011 | A study on legislative and policy tools for promoting the circular economic model for waste management in China | Journal of Material Cycles And Waste Management | Database search; policy review | 2003–2008 | 3 |
| Yu et al. (2013) | 2014 | Understanding the Evolution of Industrial Symbiosis Research A Bibliometric and Network Analysis (1997–2012) | Journal of Industrial Ecology | Database search; Bibliometria | 1997–2012 | 164 |

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**Aline Sacchi Homrich** is a Doctoral Researcher in Production Engineering, at the University of São Paulo (USP). She holds a BSc in Mechanical Production Engineering and has an MSc in Lean Project/Service Management from the Mechanical Engineering Department of the Federal University of Santa Catarina. She has several years of experience in energy projects, mainly hydropower plants. Currently, she collaborates as a doctoral researcher in the Industrial Engineering Department at the Polytechnic School of the University of São Paulo (USP), in Quality and Product Engineering (QEP) and in the Laboratory of Project Management (LGP) at USP. Her main research interests are Sustainable Business Models in Product Service Systems, Circular Economy,

Industrial Sustainability and Ecosystems, Operations /Projects Management, Servitization and System Dynamics for Sustainability.

**Graziela Galvão** is a Doctoral Researcher in Production Engineering, at the University of São Paulo (USP). She holds a BSc in Architecture and Urbanism and has an MSc in Project Management and Sustainability from the University Nove de Julho. She has more than ten years of experience as a project manager. Currently, she collaborates as a doctoral researcher in the Industrial Engineering Department at the Polytechnic School of the University of São Paulo (USP), in Quality and Product Engineering (QEP) and in the Laboratory of Project Management (LGP) at USP.

**Lorena Gamboa** Abadia is a Master's Degree student in Production Engineering, in Quality and Product Engineering (QEP) in the Project Management Laboratory (LGP) at the University of São Paulo (USP). She holds a BSc in Environmental Management and Analysis from the Federal University of São Carlos. Her main research interests are Sustainable Business Models, Circular Economy, Industrial Sustainability and Ecosystems, and Project Management.

**Marly M. Carvalho** is a Full Professor at the University of São Paulo (USP) in the Production Engineering Department of the Polytechnic School in Brazil. She is the coordinator of the Project Management Lab (http://www.pro.poli.usp.br/lgp) and Quality and Product Engineering (QEP) CNPq research group. She holds a BSc in Production Engineering from the University of São Paulo, and MSc and PhD degrees in the same area from the Federal University of Santa Catarina, and the Post-Doctoral Program at the Polytechnic of Milan. Marly has published 12 books and a number of articles in relevant journals and she can be contacted at marlymc@usp.br.