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Towards a consensus on the circular economy

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ABSTRACT

The growing importance of the concept of the circular economy as a way to attain sustainable development has encouraged scholars to propose different ways to understand it. Given the large number of studies done on the circular economy, their differing approaches and their multiple applications, this paper attempts to propose a consensus view of the basic notions of the circular economy framework and highlight its relationship with eco-innovation. To that end, this study carried out a systematic literature review that resulted in four main outputs: a knowledge map of the circular economy, an analysis of the main notions of the concept, principles, and determinants of a circular economy. Finally, this study brings to light some remarkable examples of eco-innovations developed for implementation in the circular economy.

1. Introduction

The concept of the circular economy (CE) has become very popular since it was introduced by policy makers from China and the European Union as a solution that will allow countries, firms and consumers to reduce harm to the environment and to close the loop of the product lifecycle (EU Commission, 2014; Murray et al., 2015). This contrasts with the entrenched, intensive linear economic activity that is depleting the planet's resources. The linear model began during the industrial revolution in the 17th century with the exploitative scientific and technological innovations which ignored the limits of the environmental and the long-term damage they were causing to society.

A shift to a CE requires eco-innovations to close the loop of the products lifecycle, get valuable products to others from waste and solve the needs of environmental resilience despite the tendency toward economic growth (Scheel, 2016). In the literature, the term eco-innovation is generally understood to mean *"the production, application or exploitation of a good, service, production process, organizational structure, or management or business method that is novel to the firm or user and which results, throughout its life cycle, in a reduction of environmental risk, pollution and the negative impacts of resource use (including energy use) compared to relevant alternatives"* (Kemp and Pearson, 2007). Carrillo-Hermosilla et al. (2010) go beyond this concept and explain that this kind of innovation improves environmental performance, regardless of whether the reduction in environmental impacts was intentional or not. Thus, CE is the manifestation of a paradigm shift, and it will require changes in the way that society legislates, produces and consumes innovations, while also using nature as inspiration for responding to societal and environmental needs (Cohen-Rosenthal, 2000; Hofstra and Huisingh, 2014).

In attempts to contribute to this change of paradigm, a considerable number of scholars have taken on the challenge of undertaking literature reviews that advance our understanding of CE. Studies have referred to circular business models (Bocken et al., 2014; Lewandowski, 2016), to the reduce, reuse and recycle (3Rs) taxonomy (Sihvonen and Ritola, 2015), and to value creation throughout the supply chain (Schenkel et al., 2015). Recently, a significant number of studies have focused on explaining the CE as a paradigm, its relationship with sustainable development (Geissdoerfer et al., 2017) and the large amount of concepts that define it (Kirchherr et al., 2017). Despite their divergent approaches, these studies share a similar purpose.

In response to this conceptual dispersion, this paper intends to propose a consensus-based CE framework in order to formalize its main aspects and to explain its relationship with eco-innovation, which we consider a fundamental concept. We have two reasons to believe that there is a need to build a consensus for the CE framework. The first reason is that a number of authors have claimed that research on the conceptual development of the CE is still required (Geissdoerfer et al., 2017) due to varying CE definitions (Kirchherr et al., 2017). Hence, there is an interest in building a

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cohesive conceptual framework from the literature and practical experience from CE applications (Fischer and Pascucci, 2017).

Given the above, we believe that a better understanding of CE through a unified perspective is necessary to boost CE implementation and make it a feasible way to attain genuine sustainable development. This need led us to propose the following research question: *What unified understanding of the CE can be derived from the academic literature?*

This study's research objective is to fill in this gap in the literature by carrying out a systematic literature review to propose a consensus on the concept, principles, and determinants of a CE to highlight the role of eco-innovation in this field. This study opens the path to systematic progress in making the CE feasible and defining future research topics, which can contribute to the implementation and spread of the concept as a transversal field of study.

This paper is divided into four sections. Following this introduction, Section 2 describes the research method used to find answers to the research question. Section 3 analyzes the outcomes of our systematic literature review and proposes a CE knowledge map based on a conceptual development CE and the relationship with the evolution of eco-innovation. Finally, Section 4 concludes with a summary of the main research results.

2. Methods

As previously mentioned, there are published literature reviews focused on CE, but they are quite divergent in their approaches. We undertook a systematic literature review to identify the concept of CE and its principles and determinants, with the purpose of consolidating published research on the topic and contributing to the creation of a convergent CE framework. Systematic literature reviews are a replicable, scientific and transparent method for defining a field of study, and they allow readers to understand the path researchers take to arrive at their findings (Tranfield et al., 2003).

We followed the procedure from Tranfield et al. (2003), which comprises three steps: planning, execution and reporting. In the planning step, we define the keywords of interest and a protocol for implementing the method. Additionally, we select an accessible, reliable, and academic database source to execute our search. In the execution step, we search for and select articles following the planned protocol, and we create a database to classify the articles and relevant information. In the reporting step, which is presented in Section 3, we synthesize our findings according to the defined gap and we propose a research agenda for future studies.

2.1. Planning

Our research was planned according to the objective defined above, meaning that our systematic literature review and our analysis pursued the identification of a cohesive concept of CE and the description of a general framework for facilitating its application. To that end, the terms selected to undertake the search and analysis of academic articles were “circular economy” and closely related topics such as “cradle-to-cradle”, “industrial ecology” and “industrial metabolism.” These terms were reaffirmed during the content analysis of the papers as an iterative process. Moreover, to guarantee the quality of the review, we carried out the search in the ISI Web of Science database because it provided us with different levels and categories for searching within an accurate collection of indexed articles (Shepherd and Günter, 2011) that includes the most frequently cited scientists from different fields of study (Hirsch, 2005).

In addition, our data collection was supported by a content analysis, which involved organizing large quantities of text into many fewer content categories (Weber, 1990). The protocol listed in Table 1, which is based on a protocol in Stechemesser and Guenther (2012), was designed to record in a systematic way all the information found. The items in the first column represent the key bibliographic data and the publication background for each article based on the content analysis method (Krippendorff, 1989).

2.2. Execution

We first searched for the above-mentioned terms in article topics from 1990 through July 2017, and there were 1793 results. The research team then selected the academic articles, as they usually represent a serious research work with the aim of contributing to knowledge and they have been validated by the scientific community through the peer-review processes (Murray, 2013), which gave us 729 results.

From that set of results, we looked to select the papers most closely related to an economic perspective based on the fact that CE involves market benefits because of the interaction between consumers and suppliers (Hofstra and Huisingh, 2014). The categories we selected in the WoS filter were “Environmental sciences”, “Social Sciences Interdisciplinary”, “Management”, “Economics”, “Business”, “Planning development” and “Multidisciplinary Science”. This narrowed the search to 496 results (Fig. 1). From this set, we prioritized the most frequently cited articles in WoS, which means they have the greatest impact on the research community (Mohammadi et al., 2015). Then, the titles and abstracts resulting

Table 1
Review protocol and example.

Bibliographic data	Description	Example: (Peters et al., 2007)
Title	What is the title of the publication?	“China's growing CO (2) emissions - A race between increasing consumption and efficiency gains”
Author	Who is the author of the publication?	Peters, Glen P.; Weber, Christopher L.; Guan, Dabo; Hubacek, Klaus
Journal name	What journal published the paper?	Environmental Science & Technology
Journal Category	How was the journal ranked in 2015?	Q1
What was the journal's impact factor in 2015?	6.198	
Year of Publication	When was the article published?	2007
WOS citations	How many other authors have cited the paper in Web of Science?	266
Publication background		
Methodology used in the paper	What methods are used to develop the research?	Empirical analysis
Country	Which country is the subject of the paper?	China
Industry Sector	Which industry sector is the subject of the paper?	Multiple

Adapted from Stechemesser and Guenther (2012).

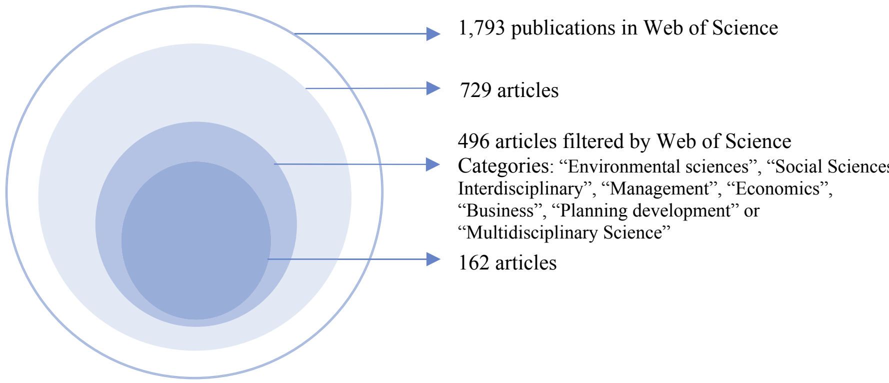

Fig. 1. Articles selection process from the Web of Science database.

from the searches (496 articles) were scanned to include the most relevant publications, meaning the publications that explain circular economy frameworks, concepts, circular design strategies, eco-innovative applications, and concepts related to industrial ecology. At the end of this final narrowing process, our review focused on 162 academic papers (Fig. 1).

As commented above, the content analysis of these 162 articles was developed as an iterative process. Moreover, taking into account that valuable research for this study was published in different databases from Web of Science, the "snowball" technique was also applied. This is a data collection method which is often used when there is difficulty in identifying a representative sample through official sources (Geissdoerfer et al., 2017; Ricci and Gunter, 1990). During that snowballing process, 13 additional publications in the form of scientific articles, books and reports were selected to be part of the literature review because they were consistently mentioned and cited in the selected articles (162), they are highly relevant to our research question, and they were suggested by our research network (Fig. 2).

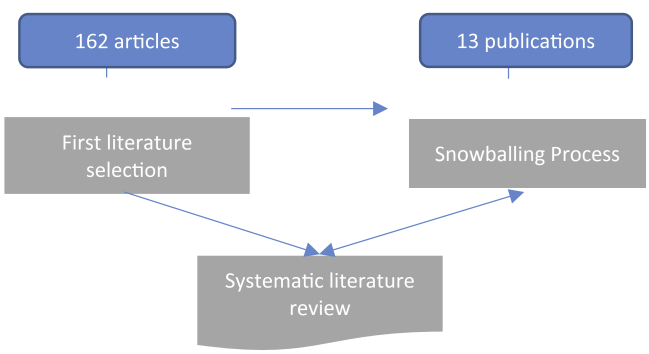

Fig. 2. Literature review process.

3. Results and discussion

This section explains the results of the systematic literature review in four parts. The first part describes the results from a descriptive and bibliographical analysis. It then analyzes CE definitions and proposes a CE knowledge map that supports the relationship between CE and eco-innovation and is quite useful for proposing a consensus on the CE. The third part includes a discussion about principles and CE determinants. Finally, we highlight some cases of regenerative and cyclical eco-innovation that has enabled mainly firms to implement the CE.

3.1. Descriptive analysis

The execution phase described above yielded the total of 175 publications that were included in this study. The oldest source analyzed was published in 1969 and the most recent one is from July 2017 (Fig. 3), except for one research paper published in

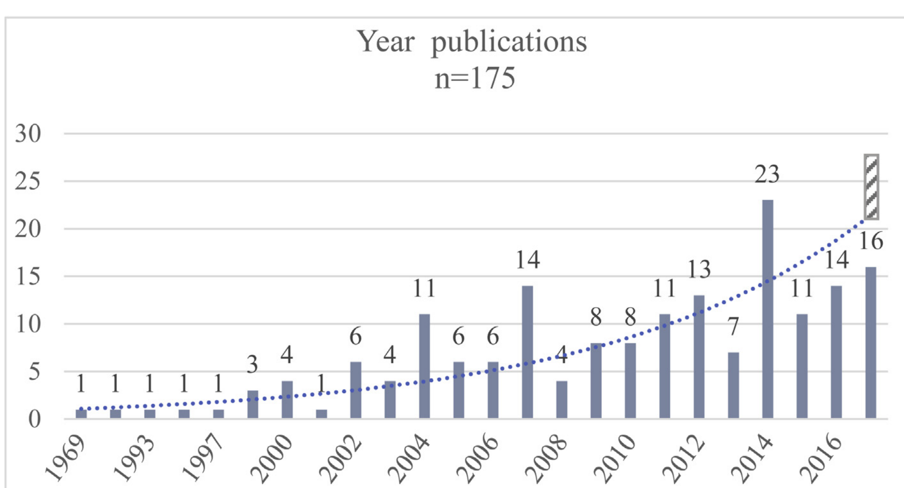

Fig. 3. Years of publication (status as of July 30, 2017).

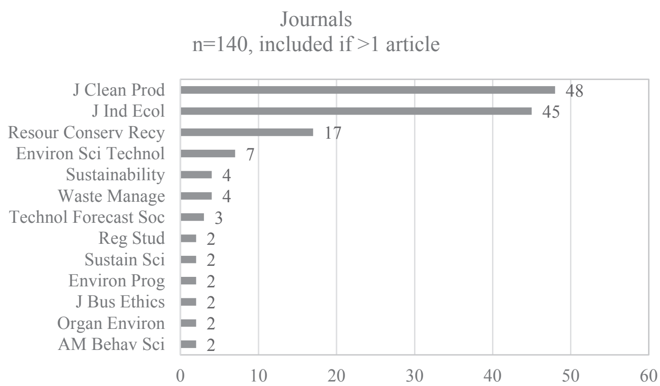

Fig. 4. Most important journals (status as of July 30, 2017).

September 2017 (Kirchherr et al., 2017), which was included because of its importance for this paper's aim.

Ninety percent of the papers were published after 2003 (153 papers), when the Chinese government started to promote CE, even though China's CE Promotion Law did not go into effect until 2009 (Wu et al., 2014). The trend shows that research topics related to CE are becoming more important within the research community. Moreover, of the terms that were selected for the initial search, "China" is the word that was most frequently included in the article titles (35 articles) and in keyword tags (24 times), which is congruent with the review by Geissdoerfer et al. (2017). This result is evidence of the clear influence that China has in CE research and implementation. Indeed, China plays a significant role in the literature given that Chinese industrial development has led to a decrease in poverty and the improvement of its citizens' quality of life (Ravallion and Chen, 2007). Nevertheless, the high social and environmental cost they paid for a linear economy is not a secret; the environmental impact caused by producing goods in today's China is greater than the impact caused by many other regions (Peters et al., 2007). Along similar lines, it is possible that peak in the statistics in 2014 (Fig. 3) is due to the inclusion of CE in the European Union agenda (EU Commission, 2014), drawing scholars' attention to the topic.

The papers selected showed that the most important journals for topics related to CE and Industrial Ecology (meaning the journals published more than one article) are those with a recognized research background in prevention, cleaner production, environmental engineering and management, such as *Journal of Cleaner Production* and *Journal of Industrial Ecology* (Fig. 4). Topics related to CE and Industrial Ecology are also present in high impact journals related to resource conservancy, sustainability, waste management and environmental sciences.

The quality of the selected papers was assessed through the WoS impact factor and according to Journal Citation Reports (JCR) categories. Of the 175 publications, 171 were scientific articles, and 150 articles fall in the Q1 category, and all the corresponding journals have an average impact factor of 3.3480. The journal with the highest impact factor (40.137) is *Nature*.

3.2. Conceptual development of the circular economy

In our attempt to find a coherent and cohesive definition of the CE, the research team carried out a content analysis of the CE terms discovered in the literature review. A review of the selected papers showed few explicit definitions of CE (Table 2), even though there

Table 2
Explicit definitions of circular economy, ordered from most recent to least recent.

Author	Explicit definition of circular economy
Kirchherr et al. (2017, p. 224)	"A circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations."
Geissdoerfer et al. (2017, p. 766)	"a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. Second, we define sustainability as the balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations."
Ghisellini et al. (2016, p. 16)	"Circular economy is defined by Charonis (2012), in line with The Ellen Macarthur Foundation vision (2012), as a system that is designed to be restorative and regenerative."
Stahel (2016, p. 435)	"A 'circular economy' would turn goods that are at the end of their service life into resources for others, closing loops in industrial ecosystems and minimizing waste. It would change economic logic because it replaces production with sufficiency: reuse what you can, recycle what cannot be reused, repair what is broken, remanufacture what cannot be repaired."
Gregson et al. (2015, p. 9)	"The circular economy seeks to stretch the economic life of goods and materials by retrieving them from post-production consumer phases. This approach too valorizes closing loops, but does so by imagining object ends in their design and by seeing ends as beginnings for new objects."
Haas et al. (2015, p. 765)	"The circular economy (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." "CE, material flows are either made up of biological nutrients designed to re-enter the biosphere, or materials designed to circulate within the economy (reuse and recycling) (GEO5 2012)."
Ma et al. (2014, p. 506)	"A circular economy is a mode of economic development that aims to protect the environment and prevent pollution, thereby facilitating sustainable economic development."
Park et al. (2010, p. 1496)	"The CE policy seeks to integrate economic growth with environmental sustainability, with one element relying on new practices and technological developments, similar to the application of environmental modernization technology."
Xue et al. (2010, p. 1296)	"Circular economy is the outcome of over a decade's efforts to practice sustainable development by the international communities, and is the detailed approach towards sustainable development (Moriguchi, 2007)."
Yang and Feng (2008, p. 814)	Circular economy is an abbreviation of "Closed Materials Cycle Economy or Resources Circulated Economy" (…) "The fundamental goal of circular economy is to avoid and reduce wastes from sources of an economic process, so reusing and recycling are based on reducing."
Geng and Doberstein, (2008, p. 232)	"mean the realization of a closed loop of materials flow in the whole economic system." (…) "implying a closed-loop of materials, energy and waste flows"
Peters et al. (2007, p. 5943)	"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."

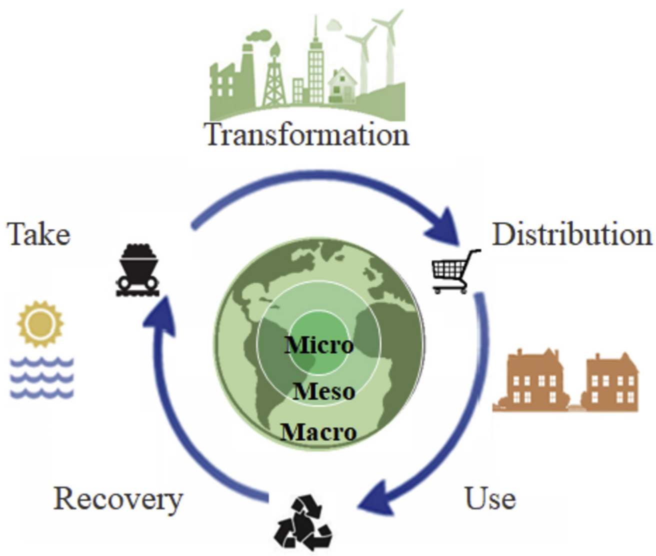

Fig. 5. Circular economy cycle.

are more than a dozen explicit meanings for the most developed topics, like IE.

Generally, the CE is outlined as a cycle of the extraction (take, in Fig. 5) and transformation of resources and the distribution, use and recovery of goods and materials (Park et al., 2010; Stahel, 2016). First, firms take resources from the environment to transform them into products and services. Then, they distribute the products or services to consumers at sale points or to other firms, and the products/services are used by consumers in the market. At this point, the CE proposes to close the loop through the recovery of goods. In this stage, Stahel (2016) has stressed the importance of innovation to recover and enrich the used materials either through the environment or industrial processing instead of disposing of them or simply wasting them (Fig. 5).

Moreover, we find general agreement on the fact that CE is characterized by three different levels of research and implementation: micro, meso and macro (Yuan et al., 2006). At the micro, or enterprise, level, companies are focused on their own improvement processes and eco-innovation development. In addition, at this level there is a positive relationship between a company's environmental management maturity level and its willingness to implement CE because of the positive impact it has on its prestige among consumers and the associated reductions in cost. (Ormazabal et al., 2016). The meso level includes companies which belong to an industrial symbiosis that will benefit not only the regional economy but also the natural environment (Geng et al., 2012). Lastly, the macro level is highly focused on the development of eco-cities, eco-municipalities or eco-provinces (Yuan et al., 2006) through the development of environmental policies and institutional influence (Fig. 5).

Furthermore, we found that the concept of CE has been developed thanks to different approaches from disciplines such as ecology, economy, engineering, design and business, meaning it has been developed from a multidisciplinary perspective (Fig. 6a). The path that society has traveled to the CE can be divided into three major stages (Fig. 6a). The first stage is the linear economy, which began with the industrial revolution and overexploitation of resources. This stage was interrupted in the 60's by the notable interest in the environment, especially from publications by ecologists, such as Carson's *Silent Spring* (Carson, 1962), and by economists like Boulding (1966), who posited that Earth could work as a cyclical ecological system, thereby recirculating the limited resources and making them unlimited.

A second stage begins with the awakening of the first theoretical and practical initiatives of industrial ecology founded by Ayres and Kneese (1969) and Ayres (1989), who explained that industrial activities can work like a metabolism, where different actors can be integrated through their wastes and resources, which continuously circulate through the resource inventory of the system. In this stage, interest for a greener economy emerged. A green economy is defined by the United Nations Environment Program (UNEP) as "one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (UNEP, 2011). The concept of a green economy has played a key role in the environmental strategies of governments and institutions, but it tends to be associated with weak sustainability actions and with fewer adaptations to people's way of living. Furthermore, weak sustainability states that economic benefits can substitute "human capital" and "natural capital", and it does not aim to achieve deep transformations of the current linear production and consumption system (Loiseau et al., 2016).

Finally, the third stage starts at the beginning of the 90's when Pearce and Turner (1990), following Boulding's research, coined the term "circular economy" to explain the feasibility of taking into account environmental awareness in economic flows by closing industrial loops (Pearce and Turner, 1990; Xue et al., 2010). From the literature review, differences do exist in recent definitions of circular economy, e.g. ' … a new development strategy …", "… policy … ', ' … mode of economic development … ' and ' … way to protect the environment and resources … ' (Table 2).

Park et al (Park et al., 2010). and Ma et al (Ma et al., 2014).

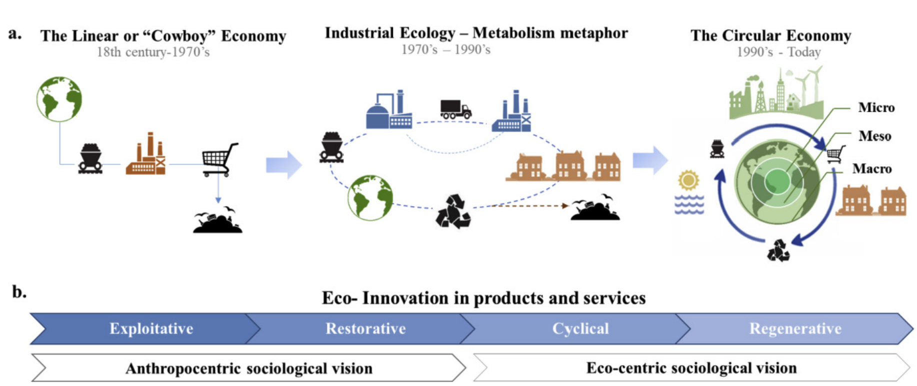

Fig. 6. Proposed circular economy knowledge map. Based on Ayres (1989), Boulding (1966), Chertow and Ehrenfeld (2012), Hofstra and Huisingh (2014), Pearce and Turner (1990), Pope Francis (2015) and Yuan et al. (2006).

highlight the role of CE as a policy and model that aims to promote economic growth in a way that is sustainable and respects nature (Table 2). Yuan et al. (2008) and Haas et al. (2015) focus on the strategic value that CE has "by closing economic and ecological loops of resource flows". The most recent definitions include new observations such as the multi-level vision of the CE concept explained before (micro, meso and macro level), and the important role of sustainable business models (Kirchherr et al., 2017). Geissdoerfer et al. (2017), meanwhile, emphasized that CE must be a regenerative system (Table 2). Despite the divergence in their focus, most of scholars agree in the fact that CE is part of the solution for achieving sustainable development (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Ma et al., 2014; Xue et al., 2010).

Considering these valuable contributions (Table 2), we believe that four relevant components are necessary to establish the concept of CE: 1) the recirculation of resources and energy, the minimization of resources demand, and the recovery of value from waste, 2) a multi-level approach, 3) its importance as a path to achieve sustainable development, and 4) its close relationship with the way society innovates. In the next section, we will argue the importance of this last component.

3.3. Circular economy and eco-innovation

As the previous conceptualization shows, the CE requires innovations in the way industries produce, consumers use and policy makers legislate. In this way, environmental innovation or eco-innovation has evolved over time as the CE has; this chronological evolution is due to the increase of the complexity and dynamism of the economy and markets (Mejía-Villa, 2016). The evolution of eco-innovation has been theorized by Hofstra and Huisingh (2014), who explain there has been a sociological change from an anthropocentric to an eco-centric vision of nature, which has been influencing the way that society evolves and develops environmental innovations (Fig. 6b).

Hofstra and Huisingh (2014) distinguish four types of eco-innovations: exploitative, restorative, cyclical and regenerative. The first two are associated with an anthropocentric sociological vision of the world, where the human necessities are the priority and the idea of growth comes from the traditional linear economy without taking into account the thermodynamic limits of energy consumption (Ehrenfeld, 2000) (Fig. 6b). Exploitative eco-innovations pay little attention to environmental issues but meet legal requirements and pursue cost decreases. Restorative eco-innovations tend to develop solutions for the damage done, meaning they are corrective innovations. Moreover, they are eco-efficient in minimizing resource use and emissions.

The second two types of eco-innovations, cyclical and regenerative, come from the recent eco-centric sociological vision, where the ecosphere becomes important and humans are part of nature rather than its owners (Hofstra and Huisingh, 2014). Even Pope Francis has been clear about the responsibility that we humans have with respect to taking care of the environment and adopting the role of managers of the planet rather than owners (Francis, 2015) (Fig. 6b). Cyclical eco-innovations connect humans and nature with the ecosystem to a higher degree, and they also improve the capacity of systems to close the loops. Finally, regenerative eco-innovations are very closely related to the eco-system's ability to create added value for humans and nature (Hofstra and Huisingh, 2014). As a consequence, humans have to consider the role of their actions in nature's capacity for resilience if our needs keep growing (Yuan et al., 2008).

In analyzing the conceptual development of the CE, the three stages of evolution throughout history and the eco-innovation evolution, they all illustrate a chronological relationship among. As a consequence, we propose a CE knowledge map (Fig. 6) that includes this relationship, since humans' perception of nature and their actions are crucial elements in changing the social and economic systems which continuously affect the environment. CE implementation requires cyclical and regenerative eco-innovations to achieve a sustainable development that meets expectations for economic, environmental and social prosperity in the short-, long-, and longer term (Huesemann, 2004; Lozano, 2008).

With the aim to propose a cohesive and inclusive concept of CE based on the academic literature reviewed, we propose the following definition of CE: *The circular economy is an economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops, and facilitate sustainable development through its implementation at the micro (enterprises and consumers), meso (economic agents integrated in symbiosis) and macro (city, regions and governments) levels. Attaining this circular model requires cyclical and regenerative environmental innovations in the way society legislates, produces and consumes.*

3.4. Principles of CE: 3Rs and sustainable design strategies

A large number of the articles reviewed describe a number of principles that lay the foundation for the transition to the CE, although there is still a lack of agreement on this issue as Kirchherr et al. (2017) demonstrated. In our review of the selected articles, we found that two different group of principles have been defined. First, the most common and frequently mentioned group of principles are the 3Rs (reduce, reuse and recycle), as cited by authors such as Ghisellini et al. (2016), Haas et al. (2015), H. Wu et al. (2014) and Yuan et al. (2008). Two authors are especially strong proponents of these principles: Wang et al. (2014) state that "a circular economy is based on the 'reduction, reuse, recycle' principle, consisting of the characteristics of low consumption, low emission and high efficiency", while Yong (2007) affirms that "the 3Rs principle — well known as reduce, reuse, and recycle — is a good principle guiding how to implement the circular economy in practice".

Secondly, a significant number of publications and reports by organizations like the Ellen MacArthur Foundation (2013) use sustainable design strategies (SDS) as the "official" CE principles. The three most popular design strategies are eco-design guided by the life cycle assessment (LCA) of a product, nature-inspired design strategies (NIDS) such as biomimicry, where "nature is the mentor" (Benyus, 2002), and the cradle-to-cradle or "C2C" tenets which aim to inform humans about design. The three tenets are: waste equals food, use current solar income, and celebrate diversity (De Pauw et al., 2014; McDonough and Braungart, 2002; van der Wiel et al., 2012). In addition, an empirical study developed by De Pauw et al. (2014) revealed that NIDS encourage design students to include a greater range of diverse solutions within the specific context of the product-system and to design with a more functional approach.

However, many scholars now argue that NIDS does not meet all the parameters of the measures based on lifecycle assessment (Bjorn and Hauschild, 2013), especially if the environmental impact is concentrated in the distribution and use stages (Llorach-Massana et al., 2015). As a consequence, NIDS should be applied in the CE stages of resource extraction and transformation, and the recovery of goods and materials. Moreover, the present study proposes that the eco-design strategy can cover this gap and be useful in reducing environmental impacts when the ownership of goods and services is transferred to consumers. In this vein, we believe that the use of different SDS may be combined and applied to design sustainable goods and services, which can subsequently be reduced, reused and recycle for the CE.

Moreover, we also believe that both the 3R principles and sustainable design strategies (SDS) shape the CE framework and can coexist, but they should be understood as having different functions and working at two different levels. According to Yuan et al. (2008) and Yang and Feng (2008), the 3R principles are clearly transversal in the CE model, meaning that they can be applied throughout the whole cycle of production, consumption and return of resources. However, we view SDS as catalyzers, because they are used as guidelines for designing eco-innovative goods and services which could be reintroduced to the system in the long term as biological or technical resources (Braungart et al., 2007; De Pauw et al., 2014) (Fig. 7).

3.5. Circular economy determinants

As we mentioned in the introduction, CE requires innovative solutions to legislation, production, and consumption that are in line with sustainable wealth creation (Scheel, 2016). These aspects fit perfectly with the three determinants of eco-innovation defined by Horbach (2008), Oltra (2008) and Horbach et al. (2013): regulation and policy, supply side, and demand side. We therefore analyzed the selected articles for these three determinants (regulation and policy, supply side, and demand side) in terms of how they are applied to the CE and how they are interrelated and interact (Fig. 8).

Regulation and policy determinants influence and motivate consumers' and suppliers' environmental practices, paving the way towards CE implementation. In the case of consumer behavior, policy makers may propose instruments to decrease resource demand, such as incentives for smaller dwellings, repairing or renovating products (including electronics) instead of purchasing new ones, and encouraging a sharing economy (Kalmykova et al., 2016). Moreover, regulation and policy determents should support the development of innovative solutions for waste collection (Ilic and Nikolic, 2016), economic incentives for cleaner production, the reduction of political barriers like inefficient consumption taxes, and low-interest loans (Geng and Doberstein, 2008; Zhu et al., 2015). Although Xue et al. (2010) claimed that policy makers tend to promote economic aspects instead of public awareness and

Fig. 7. Proposed integration between circular economy principles and sustainable design strategies (SDS). Based on Benyus (2002), De Pauw et al. (2014), McDonough and Braungart (2002) and van der Wiel et al. (2012).

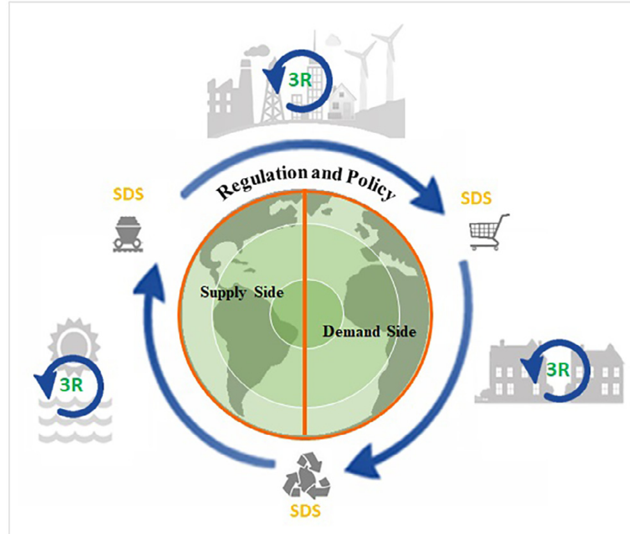

Fig. 8. Eco-innovation determinants towards CE.

financial support, Ilic and Nikolic (2016) have shown that successful economic incentives may drive environmental and public health improvements. Andersen (2007) explained that the understanding of the economic costs of environmental externalities may support and expand the analysis of the virtues of a more circular economy.

Supply side determinants include technological capabilities, cost savings from efficient production, market structure and organizational innovations. Several articles highlight the importance of innovation and a technology-oriented approach to a CE, which allows for the reduction or stabilization of resource demand and the satisfaction of human needs (Ehrenfeld, 2004). To that end, innovative technologies can be developed at every level of impact: 1) the micro level inside local businesses, 2) the meso level at which interconnected industries operate, and 3) the macro level formed by institutions and the region as a whole. This will effectively close the industrial loops at every level (Deutz and Gibbs, 2008). Then, technological information and technological infrastructure can be exchanged to make progress on industrial ecology initiatives since micro to macro levels of performance (Braungart et al., 2007; Thomas et al., 2003). Additionally, some empirical cases show that technological modernization and waste management can mitigate the unsustainable use of natural resources (Huang et al., 2014) and decrease the productions costs. Authors like Allen (1993) have realized that a significant portion of the current “waste” includes underutilized raw materials, but they can be potential circular materials for industries (Braungart et al., 2007; Gibbs et al., 2005). What's more, improvements in design and technology can drive the extension of product life, reducing the demand for raw materials and energy (Bakker et al., 2014).

The interconnection capacity is a supply side determinant which is closely associated with organizational innovation. This determinant consists of two components: geographical proximity and the affinity of company management to work in an interconnected manner. Geographic proximity has been identified as a key component in successful symbiosis cases (Chertow and Ehrenfeld, 2012) because it facilitates the sharing resources, it reduces transportation costs and it achieves greater collective benefits (Schiller et al., 2014), which means lower emissions and decreased depletion of resources. At the same time, empirical studies highlight that spontaneous symbiosis relations appear when participants share a context and the goal of cooperation (Chertow and Ehrenfeld, 2012);

it also means that some companies have a greater willingness to undertake corporate changes. Additionally, having a capacity for interconnection also helps companies overcome technological challenges and share knowledge to optimize resources and benefits (Zhu et al., 2015). This determinant is associated with an organization's success in the market, as firms that form symbiotic relationships usually change the way they do business and move to an environmental management approach (Cohen-Rosenthal, 2000; Geyer and Jackson, 2004).

Another supply side determinant is the market system because the successful application of CE principles in companies is closely related to the profitability of circular resource use (Andersen, 2007) and companies' capacity to change their business models into sustainable and competitive ones (Yang et al., 2014). Moreover, the value created by companies should respond to market demands, meeting the customers' needs and expectations to make the CE feasible. In our review, we found multiple business models that are compatible with the CE, even though they are still at an early stage of development. These include models focused on recycling and remanufacturing (Geyer and Jackson, 2004; Ongondo et al., 2013; Zhang et al., 2011), creating new business through a circular Canvas method (Lewandowski, 2016), decreasing ownership and increasing the rental of services (Bakker et al., 2014), and practicing dematerialization (Ehrenfeld, 2000; Yang et al., 2014), among others.

Moving to the demand side determinants, these are related to consumer needs, which includes their environmental awareness, their preferences for sustainable products and the expected success in the market. Implementing a CE over the long term will depend on consumers' perception of added value (Cohen-Rosenthal, 2000) and their social perception of sustainable products. In this regard, the growing social awareness of product components and their chemical origin have given rise to environmentally-oriented consumer behavior (Matus et al., 2012). In addition, the emerging environmental education programs in schools and universities increase people's interest in the value of nature (Finlayson et al., 2014; Gao et al., 2006; Geng et al., 2009), its resources and the way societies manage them (Matus et al., 2012). Moreover, the constant changes in market trends and customer preferences should be managed by firms that use CE strategies such as reverse logistics for waste management (van der Wiel et al., 2012) and the design of sustainable products which can be recovered through biological cycles (return to the biosphere) or technical cycles (return to the techno sphere) (McDonough et al., 2003). However, if recycling rates are lower than the increase in consumption, the CE won't be feasible (Kalmykova et al., 2016).

The study of the three CE determinants are interrelated. The regulation and policy determinants build the legal framework for action on the supply side and the demand side. The supply side determinants mainly affect issues that are controlled by and undertaken in firms or group of firms that form industrial metabolisms. Finally, the demand side determinants are associated with the behavior of consumers and their acceptance of eco-innovative products in the market. Eco-innovations in the market and new business models circle back and motivate changes in the regulation and policy determinants in an iterative process (Fig. 8).

3.6. The Eco-innovation performance to move forward on the CE

Going back to Section 3.2, eco-innovation that facilitates the CE should represent benefits for the environmental regeneration, improve the capacity of systems to close the materials loops and create value for nature and humans. Hofstra and Huisingh (2014) claimed that "from an economic perspective, it is clear that commercial applications are essential for innovational success". Thus, the success of CE is directly related to the eco-innovations developed to that end. For that reason, our literature review yielded a set of examples of eco-innovation oriented towards achieving the CE and following our content analysis, we propose a typology of eco-innovations. The most recognized classifications of innovations are the four types of innovation (product, process, marketing and organizational innovation) defined by the Oslo Manual (OECD/Eurostat, 2005) and the ten types of innovation proposed by Keeley et al. (2013) (profit model, network, structure, process, product performance, product system, service, channel, brand and customer engagement). Together they provided us with the conceptual guidelines for classifying and proposing a typology of eight kinds of eco-innovation:

1) Business model innovations, which are related to the way that companies create and capture value.
2) Network innovations, which are created by working in symbiosis with other companies.
3) Organizational structure innovations in the development of new organizational and management practices to support environmental strategy.
4) Process innovations, which are associated with the way that companies make their products or offer services.
5) Product innovations, which are related to the quality and functionality of the products.
6) Service innovations in the CE context tend to be developed to increase the use of a product by decreasing its ownership; this means that a product can be used many times by different people, rather than being used by a single owner for a brief period. Thus, their impact on resource consumption is low, but such innovations also have an impact on the service infrastructure.
7) Market innovations, which are created through communication channels with the customer, brand values and the positioning of the product.
8) Customer engagement innovations, which focus on customer experiences, and meeting their needs or desires.

In this context, we suggest that this change of paradigm will be visible through eco-innovations, which are the tangible results of the CE paradigm. Furthermore, our systematic literature review found numerous descriptive and empirical studies that show how both CE and industrial ecology approaches have resulted in cyclical and regenerative eco-innovations, as shown in Table 3.

According to these 19 representative examples selected from our literature review, most of them have an impact on more than two types of eco-innovations (11 examples). The four business model innovation examples have shown how different organizations have increased their competitiveness, financial efficiency and profitability through different applications of CE, even in public procurement (Witjes and Lozano, 2016). Moreover, organizational structures sometimes have to change in order to support an environmental strategy, as was the case in the Tianjin Economic-Technological Development Area (TEDA) in a Chinese eco-industrial park (Yu et al., 2014). However, in this classification the most frequent innovations are in processes (14 examples), such as the eco-industrial parks at Tianjin, which have improved the way their material flows work in symbiosis, and as a consequence their processes are more efficient and profitable (Shi et al., 2010). Network and market innovations are the next most frequently implemented types, and they are related to cooperation efforts with other stakeholders and the environmental innovations that have an impact on the distribution, price and brand performance of products or services. Some examples are in the mining-minerals, furniture and appliance industries (Linton et al., 2002; Rossi et al.,

Table 3
Examples of eco-innovations developed for CE implementation, ordered by country of analysis and for the eight eco-innovation types proposed.

Reference	Country of analysis	Sector	Business Models	Networks	Organizational structures	Processes	Product	Services	Market	Customer engagement
Shi et al. (2010)	China	Multiple		X		X				
Yang and Feng (2008)	China	Sugar		X		X	X			
Hu et al. (2011)	China	Tannery		X		X	X			X
Park et al. (2010)	China	Technology		X		X			X	
Gao et al. (2006)	China	Chemical engineering					X			
Yu et al. (2014)	China	Technology		X	X	X			X	
Zhu et al. (2015)	China	Multiple			X				X	
Reyes-Bozo et al. (2014)	Chile	Mining-minerals				X	X		X	
Verhoef et al. (2006)	Netherlands	Waste infrastructures				X		X		
Sevigne-Itoiz et al. (2014)	Spain	Mining-minerals	X	X		X			X	
Kuo et al. (2005)	Taiwan	Tourism				X		X		
Knoeri et al. (2016)	UK	Services		X		X		X		
Rossi et al. (2006)	US	Furniture				X	X		X	X
Linton et al. (2002)	US	Appliance	X			X			X	
Bakker et al. (2014)	Multiple	Appliance				X	X			X
Lewandowski (2016)	Not Specific	Multiple	X		X					
(Cohen and Muñoz, 2016)	Not Specific	Multiple		X				X		X
Witjes and Lozano (2016)	Not Specific	Public procurement	X		X	X		X		

2006; Sevigne-Itoiz et al., 2014).

The product innovations found are closely related to the increase in environmental quality and functionality. For example, the tannery industry has mainly developed network and processes innovations, which has a direct impact on reducing the environmental impact of their products without compromising their quality, as Hu et al. (2011) explain. Service innovations are highly focused on infrastructures that decrease ownership and increase rental services, which has been called the performance economy. Finally, far too little attention has been paid to customer engagement innovations, even though certification aspects have briefly brought up the topic (Yong, 2007). In this area, the sustainable consumption platforms to loan, share or resell pre-owned goods (Cohen and Muñoz, 2016) have become the most notable innovation.

These CE implementation cases have required eco-innovative solutions that benefit the economy, society and the environment. In this way, the CE could be configured into a system that can achieve true sustainable development from the implementation of regenerative and cyclic eco-innovations.

4. Conclusions

In addressing this paper's research question, our research has extended our knowledge of the foundations of a CE and proposes that four main components should be included in definition of CE: 1) the recirculation of resources and energy, the minimization of resources demand, and the recovery of value from waste, 2) a multi-level approach, 3) its importance as a path to achieve sustainable development, and 4) its close relationship with the way society innovates. These four components can help scientific community and policy makers to get a consensus in this field. Therefore, we defined circular economy as *an economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops, and facilitate sustainable development through its implementation at the micro (enterprises and consumers), meso (economic agents integrated in symbiosis) and macro (city, regions and governments) levels. Attaining this circular model requires cyclical and regenerative environmental innovations in the way society legislates, produces and consumes.* Moreover, the introduction of CE has been applied in various ways, e.g. ' … a new development strategy …", "… policy … ', ' … mode of economic development … ' and ' … way to protect the environment and resources … ' (Table 2).

The exploration of the CE concept led us to another important finding; namely, the building of a knowledge map that explains that CE is a consequence three stages of social, industrial and economic changes which are directly related with the way society innovates. However, according to this knowledge map (Fig. 6), CE is not a "panacea of sustainability" and we do not intend for it to be the "last word". However, it clearly represents the most advanced and recent manifestation of the paradigm shift. As Stahel (2016) points out, "concerns over resource security, ethics and safety as well as greenhouse-gas reductions are shifting our approach to seeing materials as assets to be preserved, rather than continually consumed".

Just as several CE definitions exist, multiple CE principles were found. A contribution of this study is the distinction of the transversal 3R principles and their "catalyzers", which are sustainable design strategies (SDS) such as NIDS and eco-design. This means that the 3R principles can be applied throughout the whole cycle of production, consumption and return of resources, while the environmental design strategies work as catalyzers and guidelines for designing goods and services which can be reintroduced in the system in the long term as biological or technical resources. The scope of this study was limited to the distinction of the transversal 3R principles and their "catalyzers", but further research should be done to investigate the application of SDS in each level of performance of CE and in specific sectors.

This is the first time that eco-innovation determinants have been applied to explore the CE because of the importance of innovative solutions to legislation, production, and consumption in CE implementation. The three eco-innovation determinants applied to CE were regulation and policy, supply side, and demand side. Our analysis explained their composition and how they interact in CE. In short, the regulation and policy determinants build the CE legal framework that supports the supply side actions such as cleaner production, the development of industrial metabolisms and sustainable business models. The demand side determinants, mainly represented by consumers, should be able to accept eco-innovative products in the market and acquire sustainable behavior.

To meet our goal of proposing a consensus on basic CE notions, we highlighted the role of eco-innovations as a way of creating a CE. Based on the examples provided in this paper and their applications in different sectors and countries, we believe that the study of eco-innovation from an eco-centric perspective must be a clear objective for the feasibility and success of CE. This finding has important implications for further work on the eco-innovation types and their influence in CE multi-level performance and success.

Finally, several important limitations of our work need to be considered. First, the current study has mainly examined academic articles. Second, the search for articles was carried out in only one database (ISI Web of Science), although considering that valuable research for this study was published in other databases, the "snowball" technique was also applied. Third, the subjective assessment of the articles and their understanding in the CE scenario which is based on the researchers' analysis.

Future studies should explain in greater depth how this theoretical knowledge can be easily transmitted to practitioners and how the CE determinants can be supported through the micro, meso and macro levels. Moreover, this study opens the way to proposing how this advanced manifestation of the paradigm shift could evolve, and whether society could really live in balance with nature.

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