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Eco-innovation in the transition to a circular economy: An analytical literature review

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ABSTRACT

In the ongoing sustainability debate, the circular economy (CE) has been steadily gaining ground as a new paradigm. At the same time, eco-innovation (EI) has been recognised as a key element in carrying out the transition from a linear to a circular system of production and consumption. However, little information can be found concerning whether and how EI can actually facilitate the change to a CE. While extensive literature on EI, and a growing body of research exploring the CE, already exist, there is, as yet, no comprehensive understanding concerning the connections between these two concepts. Drawing on academic contributions from the fields of EI and CE, this analysis seeks to clarify and synthesise findings at the intersection of these two fields. The aim is threefold: derive literature-based working definitions of CE and EI; review the role of EI at CE's macro, meso, and micro levels; and characterise CE-inducing EI in terms of targets, mechanisms and impacts. Our literature review shows that an EI-driven techno-economic transition to a CE requires specific solutions, i.e. different forms of EI-driven "clean congruence" at distinct levels of operation. Generally speaking, movement toward a CE is found to be contingent on "systemic" EI, that is, not only intense in technology but also involving dynamic and holistic combinations of service innovations and novel organisational set-ups.

1. Introduction

Continued human use and abuse of natural resources is pushing global ecosystems to the brink. Several global tipping points have already been reached, increasing the risk of cascading irreversible environmental changes (Rockström et al., 2009). Recent decades have highlighted the importance of decoupling economic growth and social development from resource exploitation and waste. One of the defining challenges of the 21st century seems to be how to accommodate economic development among competing countries, and the continuous rise of living standards of a world population estimated to reach 10 billion by 2050, in a context of limited natural resources without jeopardising the sustainability of the global environment (OECD, 2012).

In the light of the limitations of the conventional economy, a more circular approach is gaining traction. A view referred to as the "circular economy" (CE) has been put forward as a strategic approach, placing closed-loop thinking at the heart of businesses, industrial organisation and national agendas (see, e.g. Preston, 2012). The CE is a concept inspired on natural ecosystems and postulates moving away from a notion of a linear economy (based on unidirectional extraction, production, distribution, consumption and disposal activities) towards a permanently regenerative economy in an effort to rethink all of a product's life cycle. The CE focuses on the design of processes and products aiming to minimize negative environment and societal impacts, reducing the use of non-renewable resources, eliminating toxic and hazardous materials, and increasing product lifespan, as well as maximising the potential for reusing products and recovering materials (IAU, 2013). It proposes models for value creation that support sustainable economic development, through loops of reuse, restoration and renewability, where waste is residual or converted into an input into other processes thus shifting the emphasis to the provision of

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functionality and "service" rather than ownership and material production (EMF, 2012; Stahel and Reday-Mulvey, 1981).

Building on early definitions CE ideas have gained additional relevance as a research topic over the last decade (Andersen, 2007), driven by organisations such as the United Nations (UNEP, 2014) and the European Union (EC, 2015) as well as the work of private agents as the Ellen MacArthur Foundation (EMF, 2012, 2013, 2014). Nevertheless, "while businesses and governments are recognising the need for change, there is confusion on what needs to be changed and how it can best be accomplished." (Schulte, 2013, p. 47).

Meanwhile, eco-innovation (EI) has been emphasised as a core driver for change in the transition to sustainability (Kemp, 2010). It is defined as innovation, in all of its forms (product, process, marketing, organisational - see OECD, 2005), yielding both ecological and economic gains (Carrillo-Hermosilla et al., 2010). In other words, the concept has been recognised as a key element in the development of competitive technologies and institutional forms (including new business models) that allow "environmental benefits", including greater efficiency in consumption and use of resources (EC, 2012). In the policy arena, EI has been called "a catalyst" of a CE (Potočnik, 2014) and a key component in the transition from a linear to a circular system of production and consumption (EIO, 2016).

However, an analysis of the intersection of the CE and EI concepts seems lacking, with few studies considering the explicit importance of EI towards a CE (EIO, 2016). If aligning innovation activities with a more sustainable path is a central requirement for a techno-economic paradigm shift (Mirata and Emtairah, 2005), how can the innovation agenda be geared towards a CE? What changes are instrumental for such a structural break? Can the concept of EI bring about the changes required for the CE framework to be deployed and reinforced?

The way in which EI is to drive the pro-CE transition remains an insufficiently addressed issue. Using an innovation studies perspective this paper aims to contribute to the sustainability transition debate. More comprehensive research seem instrumental to understand such a transformative transition, driven by dynamic and holistic CE-friendly business models and public policies. Understanding the role of EI will help actors and institutions to better adjust and calibrate their CE efforts. Business actors, in particular, would benefit from this analysis, so as to be able to both redesign and pursue sustainable business models from the outset. As for policy makers, an integrated understanding of EI, and its relationship to CE, could underpin initiatives that take uncertainty and feedback loops into account. On the basis of a conceptually-driven literature review we propose the concept of, to mint a term, "clean congruence" as a link between the CE and EI bodies of work.

This paper seeks to provide a view of the role of EI within a CE framework by drawing on overlapping academic contributions from the fields of EI and the CE and by appraising existing insights at the point where these agendas intersect. The three main objectives of this paper are thus to: 1) derive literature-based working definitions and characteristics of EI and CE; 2) review and assess the relationship between the different dimensions of EI and the various levels of a CE, and; 3) generate an overview of the types of EI that may be most instrumental in achieving a CE.

The paper is organised as follows: Section 2 focuses on conceptual features and highlights the little charted common ground between the concepts of EI and the CE. Section 3 introduces the methodology, while Section 4 analyses the results stemming from the literature. Section 5 offers policy implications as structured by EI-CE connections. Finally, section 6 concludes by examining avenues for further research.

2. Eco-innovation and the circular economy

Even if one can intuitively argue that EI and the CE are closely related, and assume that achieving a CE without EI is unlikely, it remains to be seen in what specific ways this is so. Certainly not all EI is linked to a CE, and not all dimensions of CE require innovation. However, a zone of overlap is bound to exist. Therefore, in order to ascertain which innovations are more compatible with CE models, and how a CE is to be achieved through techno-economic change, a clearer understanding of the two concepts is useful.

2.1. Innovation dynamics in an evolving economy: the "pro-environment" family of eco-innovation related concepts

Since the seminal writings of Joseph Schumpeter (1928), it has been acknowledged that innovation is not just newness *per se*. It is, rather, a "new combination" of ideas and factors of production. Innovation is not only about technical sophistication but also about adaptation to a usage context, i.e. it is the introduction of an ingenious proposition into a specific, and sometimes quirky, economic and institutional setting (Fagerberg et al., 2004). That is to say, innovation is not simply science and technology. From this perspective, innovation is not understood to be automatic, it is neither a linear output from increased R&D, nor a passive reaction to market signals (Caraça et al., 2009).

Moreover, innovation is not necessarily better: novel outcomes are not inevitably superior to the *status quo,* from a welfare or sustainability point of view (Soete, 2013). What is technologically feasible is not necessarily ethically desirable or environmentally sound (UNEP, 2011). The 20th century mass-production technological regime was carbon-intensive and extraction-based, creating on hindsight fundamental questions about the meaning of the very notion of "progress". One implication is that innovation concepts may be liable to some revision, or even intellectual "creative destruction". As Schot and Kanger (2016), p. 25) stress, modifying "(…) the way we innovate (…)" is essential for transition. Transitions are complex dynamic processes involving a rich range of actors and discrete actions, and continued activities for a significant period of time, during which new products, services, business models and organisations emerge, either complementing or substituting incumbent ones, comprising an interacting sequence of technological and non-technological innovations (Markard et al., 2012; van den Bergh et al., 2011). As the environment became an area of prime policy concern, a cluster of concepts emerged concerning innovation focused on transition topics and broader societal challenges (Boons et al., 2013; Carrillo-Hermosilla et al., 2009; Rennings, 2000). This emerging "pro-environment" innovation agenda was beyond the scope of the industrial era (Freeman and Soete, 1997).

The entry and diffusion of an environmental angle of analysis into innovation studies has been characterised by some lexical variation. As innovation began to be conceived more and more as a dynamic process that evolves in real historical time and involves a multitude of different activities, not just formal R&D from a "high-tech" supply-side but also shaping by the social and cultural environment (Castellaci et al., 2005; Balconi et al., 2010; Guan and Liu, 2016; Lee and Walsh, 2016), innovation studies benefited from the development of other fields of research such as sustainability and transition studies (Smith et al., 2010). Sustainability and transition studies emphasise science and technology as socially embedded processes; that is, knowledge is intertwined with mental maps, the expectations of consumers, is co-constructed by skills of users, and shaped by institutional/regulatory structures and infrastructures (Markard et al., 2012). There is little consensus on how to operationalise the approach to sustainability transitions; several viewpoints co-exist and a broad range of relevant theoretical approaches, encompassing several perspectives like evolutionary economic theory (Nelson and Winter, 1982), strategic niche management (Kemp et al., 1998), technological innovation systems (Bergek et al., 2008), multi-level perspective on sociotechnical transitions (Geels, 2002, 2011) or eco-innovation (Andersen, 2008; Kemp, 2010) just to enumerate a few.

Although terminological creativity can be taken as an early indicator of conceptual restlessness, there may be a point where "label proliferation" may hamper progress in a field (Alvarez et al., 2014; Barney, 2003). As Table 1 shows, terms emerging in the literature since the mid-1990s, linking innovation to environmental concerns, have somewhat distinct, yet related, definitions. "Environmental innovation", for example, is characterised as innovation with environmental benefits (van den Bergh et al., 2011; Weber and Hemmelskamp, 2005). By contrast, "Sustainable innovation" is thought of as more rounded innovation, addressing ecological, economic and social concerns, hence being more sensitive to the spatial, temporal and cultural context (Boons et al., 2013) and focusing not only on product and process innovations, but also on organisational models (Charter and Clark, 2007). In turn, "Green innovation" is described in terms of new or improved products and processes, with the aim of fostering environmental sustainability (Cuerva et al., 2014). More recently, "Business model innovation" seems also in line with this semantic field, being defined as innovation in the way organisations create, deliver and capture value, so as to maximise societal and environmental benefits (Bocken et al., 2014; Boons and Lüdeke-Freund, 2013).

As for "Eco-innovation" (EI), its initial "end of pipe" focus has recently been broadened in scope. EI is nowadays defined as a way of enabling economic performance that does not hinder sustainable development (i.e. economically, ecologically and socially sustainable performance) and is more positively defined, by the European Commission, as "resulting in or aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment, enhancing resilience to environmental pressures, or achieving a more efficient and responsible use of natural resources." (EC, 2011a, p. 2)

EI is also acknowledged as a way to increase competitiveness without (environmental and societal) negative impacts (OECD, 2009), and an indispensable condition for sustainability (Aghion et al., 2009; EC, 2011b). In spite of some irreducible variability, some efforts towards simplification and consolidation may be useful here. In this paper EI is taken as a streamlined and all-encompassing term for environmentally-sensitive innovation, and will be used preferentially. This term refers to all types of innovation addressing ecological concerns and/or having positive ecological effects (Jabbour et al., 2015). Considering the redirection of innovation studies towards "transformative innovation" (see Schot and Steinmueller, 2016), we take the overlap between EI and CE to be a fulcrum for realising the potential of a new clean and coherent techno-economic paradigm.

2.2. Untangling and re-focusing "eco-innovation"

For the purposes of policy-making, entrepreneurial decision-making and academic research, a clear definition of EI and its dimensions is helpful. A broad, but applicable, operational definition can be offered here as: *innovation that encompasses or results in environmental damage prevention, mitigation and recovery.* This definition (Silva and Mendonca in UN, 2015, p. 90) includes a number of critical aspects:

- improved environmental performance (i.e. *green innovation*);
- market efficient and clean results (i.e. *environmental innovation*);
- enduring and socially responsible benefits (i.e. *sustainable innovation*);
- holistic transformation (i.e. *business model innovation for sustainability*).

This definition provides a robust way of understanding the many different facets of EI, whilst also integrating the many diverse areas of analysis already undertaken on this issue. Drawing on existing EI typologies (OECD, 2010), inspired by the innovation guidelines of the Oslo Manual (OECD, 2009), EI is considered in its three main dimensions: key types of innovation (*targets*); the

Table 1
The family of "environmentally-friendly" concepts of innovation.

	Description	References
Environmental innovation	"(…) innovation can be beneficial to both the innovating firm and the environment".	Weber and Hemmelskamp, 2005, p. 3
Sustainable innovation	"Process where sustainable considerations (environmental, social, and financial) are integrated into company systems, from idea generation through to research, development and commercialization. This applies to products, services and technologies, as well as to new business and organisational models"; also "(…) adoption of new processes and systems at societal level".	Charter and Clarke, 2007, p. 9
	"(…) sustainable innovation brings into focus the relevance of (…) the relationships with other actors (i.e., suppliers and customers)".	Boons et al, 2013, p. 11
Green innovation	"(…) innovations in products, processes or business models lead the company to higher levels of environmental sustainability"	Cuerva et al. 2014, p. 104
Business model innovations for sustainability	Business model innovations for sustainability are defined as: "(…) innovations that create significant positive and/or significantly reduced negative impacts for the environment and/or society, through changes in the way the organisation, and its value-network, create, deliver and capture value (i.e. create economic value) or change their value propositions".	Bocken et al. 2014, p. 44
Eco-innovation	"(…) innovation which is fuelled by ecological issues (…)"	Fussler and James, 1996, p. xi
	"(…) develop new ideas, behaviour, products and processes, apply or introduce them, which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets".	Rennings, 2000, p. 322
	"(…) innovation that improves environmental performance (…)"	Carrillo-Hermosilla et al., 2010, p. 1075; 2009, p. 4
	"(…) the creation of new, or significantly improved, products (goods and services), processes, marketing methods, organisational structures and institutional arrangements which - with or without intent - lead to environmental improvements compared to relevant alternatives"	OECD, 2010, p. 40
	"(…) any form of innovation resulting in or aiming at significant and demonstrable progress towards the goal of sustainable development"	EC, 2011a, p. 2

nature of the change (*mechanisms*), and; resulting effects (*impacts*). Hence, and capitalising on this discussion, EI is operationally summed up as any innovation that: a) has positive environmental impacts, and; b) directly or indirectly avoids natural capital damage, while delivering cost efficiencies, market enhancement, or regulation considerations, and; c) results in new or improved goods and services, technological and non-technological processes, marketing or organisational schemes; d) is incremental or radical, and; e) involves an actor or a plurality of actors.

2.3. Transition to sustainability through CE-inducing approaches: the family of CE-friendly concepts

For its most part the global economy remains a system where activities, from tangible production to intangible contracts, routines and regulations, take place within a linear model of open-ended "take-make-dispose" resource exploitation. Notwithstanding the growing awareness that the use of the Earth's resources cannot be limitless, and the dissemination of related concepts, such as corporate social responsibility, this linear model remains essentially unchallenged (although future-oriented debates go back a long time, see Mendonça, 2017). Moreover, moving away from this model will not be an easy task as entrenched technical systems are made stiffer by risk avoidance and special interests with much to lose in the short run (Markard et al., 2012; Schulte, 2013).

In the post-Paris COP 21 context, expectations are high, with 175 governments (174 countries and the European Union) signing the initial agreement, originally with the United States and China among them (UNFCCC, 2016). However, various actors' interests do not align well, as the promotion of national economic competitiveness, in a fiercely dynamic global market, comes to terms with the impacts of continued environmental degradation. A new set-up may need to be based on "decoupling" development from resource consumption, by focusing on extended material life-cycles, reuse, re-manufacturing and recycling (UNEP, 2011). If the need for change is increasingly recognised, the specific pathways of transition remain much less defined. A number of perspectives for framing the discussion have been proposed in the literature, which have been instrumental in shaping the current understanding of the CE. Table 2 presents salient examples of these.

Several ideas behind the CE concept are not new practices. Animal waste by-products (e.g. pelts, blood and bones) have been used at least since Neolithic times in the making of other items, such as fabrics, shelters, weapons and jewellery (Desrochers, 2000). Similarly, even in the 19th century, the potential benefits arising from cooperative arrangements between manufacturers and consumers, through by-product exchange and service bartering, were already being enacted (Simmonds 1862; 1875 in Desrochers, 2000). The integrated concept of the CE emerged in the late 20th century, alongside concerns regarding planetary-level resource exhaustion; e.g. Boulding (1966) "spaceman economy" advocacy, which stressed the need to find a new balance in a "cyclical ecological system"; and Georgesçu-Roegen's (1971) entropy approach to the economic system. CE as a label first appeared in Pearce and Turner (1990), discussed in a full chapter, where the case for the economic practicality of environmental values was developed, referring to the works of Boulding and Georgescu-Roegen, and arguing that natural systems also have waste but, unlike the traditional open-ended economy, they absorb and recycle it. The authors argued for "circular" material flows in the man-made economy. An economic system organised like nature, operating in loops, would reduce the need for new inputs, and delay the depletion of the "environment" (as a source of materials and a sink for waste). Resources should not simply end up as litter after usage, or as products that are simply designed to accommodate the next wave of supply; they should rather be transformed from one form to another, and converted back to new resources.

The notion of the CE eventually infused the field of "industrial ecology", especially in the USA, popularised by Robert Frosch and Nicholas E. Gallopoulos (1989) and Robert Ayres and Weaver (1998). Industrial ecology literature explicitly proposes the mimicking of natural systems' strategies as an industrial organisation template. It stresses the need for "material symbiosis" amongst different businesses and production processes, converting waste by-products into material inputs (Andersen, 2007, p. 133). In Europe, the industrial symbiosis concept has been taken up by many institutions and is widely used. The focus is on a "systems integration" view of companies exchanging by-products, closing each other's materials' cycles, and this is seen as an element that directly promotes CE implementation (Chertow, 2007; Lombardi and Laybourn, 2012).

In the late 1990's and early 2000's, critiques of traditional "industrial capitalism", which paradoxically both endangers the environment while also depending on it for natural resources, offered the notion of "natural capitalism" (Lovins et al., 1999). In this frame, environmental and economic benefits are based on more effective manufacturing processes, valuation, reuse and recycling of materials, in tune with CE considerations.

Other features of the CE can be found in the development of the "Cradle to Cradle" approach, and expected impacts on competitiveness, job creation, resource savings and waste prevention, emphasising the conversion of strict manufacturing into a nexus of self-feeding services (Stahel and Reday-Mulvey, 1981). This view was expanded over time by underlining the potential of services in the cleaning-up of the economy. Stahel (1982, 1997, 2010) develops the argument that "servicing" minimises the use of new inputs, and maximises the use of a product over its life-time, while benefiting both manufacturers (who retain control over assets, enhancing their maintenance and recovery) and consumers (who pay only for benefits).

Additional contributions include several concepts following the 3R principles of "reduction, reuse and recycle", which also share the notion of closed loops, including: the "zero emission" concept, which refers to systems whereby everything has its use and natural cycles are emulated (Pauli, 1997, 2010); the further development of the "cradle to cradle" model by Braungart and McDonough (2002); and the "zero waste" concept, whereby waste is diverted from landfills (Curran and Williams, 2012; Zaman, 2015; ZWIA, 2009).

With roots in different ideas and schools of thought, the CE thus emerges today as a wide-ranging concept, and all these various contributions must be considered in their specific contexts, as the CE has "different meanings and different roles and responsibilities for different stakeholders" (EIO, 2016, p. 9).

2.4. The "Circular Economy"

As the CE concept entered the policy arena it received a new boost. Germany showed an early interest in CE initiatives; for instance, its "Closed Substance Cycle and Waste Management Act" of 1996, tried to ensure environmentally-friendly schemes of waste disposal. In Japan the Basic Law for Establishing the Recycling-based Society of 2000 created a legal framework to induce a more recycling-based society (Preston, 2012; Su et al., 2013, p. 216). It was also made more practically relevant when it started to be discussed in China in 1998, and afterwards when it formally entered the language of the central government in 2002, as the country became the first to enact explicit policy regarding the CE (Geng et al., 2009b; Mathews and Tan, 2011; Zhu et al., 2010). Between 2005 and 2007, the CE concept was fostered through "two batches of circular economy pilots", in order "to promote circular economy philosophy into action, including key industries, key

Table 2
Examples of CE-related concepts.

CE related concepts	Links with CE	Focus	References
Closed-loop economy	"(…) man must find his place in a **cyclical ecological system**".	Focus on the need to "close" the loop in economical systems	Boulding, 1966, p. 9
	"(…) highlighted the potential of a **closed-loop economy** impact on competitiveness, job creation, resource savings and waste prevention".		Stahel and Reday-Mulvey, 1982, p. 93
Industrial ecology	"By analogy with natural ecosystems, an industrial ecology system (…) **maximizes the economical use of waste materials and of products** at the ends of their lives as inputs to other processes and industries".	Focus on emulating natural processes "closing the loop" in industrial systems	Frosch, 1992, p. 800
	"Industrial ecology involves **designing industrial infrastructures as if they were a series of interlocking ecosystems**".		Tibbs, 1993, p. 3
	"Moving **from linear throughput to closed-loop material and energy use** are key themes in industrial ecology".		Ehrenfeld and Gertler, 1997, p. 68
Industrial Symbiosis	"(…) industrial symbiosis (IS) can be categorized as a concept of collective **resource optimization** based on **by-product exchanges** and **utility sharing** among different colocated facilities"	Focus on industrial clusters and synergies	Jacobsen, 2006, p. 240
	Industrial symbiosis engages "(…) traditionally separate industries in a **collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products**".		Chertow, 2007, p. 314
Natural Capitalism	"Natural capitalism recognizes the **critical interdependence between the production and use of human made capital and the maintenance and supply of natural capital**".	Focus on environmental and economic benefits of more effective manufacturing processes, reuse and recycle of materials	Lovins et al. 1999, p. 3
Cradle to Cradle	"If humans are truly going to prosper, we will have to learn to imitate nature's highly effective cradle-to-cradle system (…) in which the very concept of **waste does not exist**".	Focus on design, since the conception stage, of competitive services/ products without negative environment impact	Braungart and McDonough, 2002, p. 103
Zero Waste	"Zero Waste means designing and managing products and processes to systematically avoid and **eliminate the volume and toxicity of waste and materials, conserve and recover all resources**, and not burn or bury them".	Focus on limiting waste and diverting it from landfills	ZWIA, 2009 unpaginated
	"Zero waste is a unifying concept for a range of measures aimed at eliminating waste and challenging old ways of thinking. Aiming for zero waste will mean **viewing waste as a potential resource** with value to be realised, **rather than as a problem to be dealt with**".		Curran and Williams, 2012, p. 3
	"At this moment, ZW strategy is targeted toward zero landfills through **diverting waste from landfills**".		Zaman, 2015, p. 17
Functional Service Economy	"A functional economy (…) is one that **optimizes the use (or function) of goods and services** and thus the management of existing wealth (goods, knowledge, and nature). The economic objective of the functional economy is to create the highest possible use value for the longest possible time while consuming as few material resources and energy as possible".	Focus on new business models	Stahel, 1997, p. 91
	"The Functional Service Economy is a set of innovative business models **that integrate products and services (…) to create health and jobs with considerably less resource consumption**".		Stahel, 2010, p. 2

Note: Main linkages with the CE concept highlighted in bold.

areas, key enterprises and urban demonstrations" (Dong et al., 2013a, p. 228). In 2008, the Circular Economy Promotion Law was approved, coming into effect in 2009, to improve "resource utilisation efficiency, protecting the natural environment and realising sustainable development" (Geng et al., 2012, p. 216). This orientation was reinforced in the 12th Five-Year Plan (2011–15), focusing on cleaner production and eco-industrial park development (Geng et al., 2009b; Shi et al., 2010; Xue et al., 2010).

By entering the western policy arena, for example through the 2015 "*EU Action Plan for the Circular Economy*" (EC, 2015), and by being sponsored by think-tanks (such as the World Economic Forum -WEF) and private institutions (such as the Ellen MacArthur Foundation -EMF), the CE became a topical theme undergoing intense study. This momentum seems to be related to several aspects. To start with, the CE concept has been considered more helpful and tangible than other approaches in solving environmental problems, offering at the same time both economic benefits and business solutions (Sauvé et al., 2016). Its potential for job creation, improved resource productivity, trade balance, and CO_2 emissions reduction, has been highlighted by policies in many countries, namely in Finland, France, the Netherlands, Spain and Sweden (Wijkman and Skånberg, 2015). Portugal also begun a public consultation process regarding its CE Action Plan for 2017–2020 (Grupo Interministerial Economia Circular, 2017). The concept has also been taken as an actual policy enacting device benefiting from several funding opportunities within the EU Circular Economy Action Plan (EC, 2017, 2015).

This does not mean that the CE is a consensual concept, or even that its definition is settled (J. Kirchherr et al., 2017). Many different recent definitions can be found, from international organisations, non-government organisations and academia (Table 3). Nonetheless, the definitions do highlight a set of core elements which characterise the CE as encompassing: i) input minimisation and efficient use of regenerative resources (material and energy efficiency as well as sourcing and prioritising the use of renewable and non-hazardous materials); ii) life cycle extension and systems reconceptualization (repair, re-conditioning and re-manufacturing options; procurement, new business models based for instance on sharing or re-use; design - from policy design to life-cycle approach and eco-design); iii) Output reduction valorisation and waste minimisation (recycling, networks of recovery, and valuing by-products and waste).

These components make up the CE, as a system deliberately designed to be restorative, replacing the end-of-life concept of the linear economy with new circular flows of reuse, restoration and renewability, in an integrated process, encompassing the entire value chain. In economic terms, the CE enables competitiveness through new ways of achieving more effective resource allocation, utilisation and productivity. Environmentally, the CE decreases negative externalities, and socially, it generates not only

Table 3
Examples of definitions of the CE.

Some of the most recent examples of definitions and descriptions of the CE		References
Circular economy	Regarding Chinese implementation of CE, it is defined as "(…) the realisation of a **closed loop of materials** flow in the whole economic system".	Geng and Doberstein, 2008, p. 232
	In China "The term 'circular economy' (…) is a generic term for **reducing, reusing and recycling activities** conducted in the process of production, circulation and consumption".	Standing Committee of the National People's Congress (China), 2009, Article 2
	"It incorporates myriad strategies to achieve greater **efficiency** through economies of **systems integration**".	Geng et al., 2012, p. 216
	One of the most used CE definitions is that of a "(…) **system** that is **restorative or regenerative by intention and design**".	EMF, 2014, p. 12
	In Europe, CE has been defined as a way to keep "(…)**the added value in products for as long as possible and eliminate waste**".	EC, 2014, p. 2
	The concept has integrated policy discourse as a way to "(…) boost the EU's competitiveness by protecting businesses against scarcity of resources and volatile prices, helping to **create new business opportunities** and **innovative**, **more efficient ways of producing and consuming**".	EC, 2015, p. 2
	Regarding CE characteristics "(…) essential elements of a circular economy (…) include: **refurbish, sharing/leasing, remanufacture, recovery, and repair** while **reduce** (in the sense of waste prevention and minimisation of hazardous substances) plays also a prominent role".	EIO, 2016, p. 10
	"Central elements of the circular economy include **remanufacturing and product life-cycle extension** schemes such as re-use and refurbishment".	UNEP, 2016, p. 246
	"(…) the concept of a circular economy (CE) is considered as a solution for harmonizing ambitions for **economic growth and environmental protection**".	Lieder and Rashid, 2016, p. 37
	"By **promoting the adoption of closing-the-loop production** patterns within an economic system CE aims to **increase the efficiency of resource use**, with special focus on urban and industrial waste, to achieve a **better balance and harmony between economy, environment and society**".	Ghisellini et al., 2016, p. 11
	CE "as 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**".	Geissdoerfer et al., 2017, p. 759
	"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 r**ecovering** 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".	Kirchherr et al., 2017 pp. 224-225

Note - Main CE characteristics highlighted in bold.

employment opportunities, but also, new "consumer" concepts (EMF, 2012, 2013).

In spite of its broad scope, arriving at a clear and compact definition of the CE remains somewhat elusive. A working definition of CE, in tune with the reviewed strands of analysis, could be given in terms of it being an approach towards sustainable development. This approach is achieved through several strategies aiming to reorganise production and social systems into regenerative environmentally-sound closed circuits. Its main characteristics are focused both on resource and waste minimisation, as well as processes of production and consumption designed from the outset for efficiency, reuse, repair, and recycling.

Building on the contribution of Freeman and Louçã (2001, p. 124), we take CE as a form of *clean congruence*, i.e. a state of compatibility between technological and socio-institutional subsystems that overcome the unresolved mismatches of a Fordist, carbon-intensive, depletion-prone era. As a particular type of positive congruence, CE provides the most favourable, enduring and self-reinforcing conditions for sustainability.

Three levels of analysis have been presented in the literature, on the basis of which the depth or granularity of CE implementation can be appreciated (Ghisellini et al., 2016). At a *micro* level, the CE focuses on individual actors, particularly companies (Yuan et al., 2006; Zhu et al., 2010). Examples include: eco-design and cleaner production strategies; resource efficiency initiatives; labelling systems, and; sustainable production and consumption methods (Geng et al., 2009b, 2012). At the *meso* level, the focus is on actor interaction especially inter-firm networks: industrial symbiosis; eco-industrial parks; green supply-chain management and reverse logistics (Zhu et al., 2010). As for the *macro* level, the CE is theorised at a national or global scale, with an emphasis on legislation; regulatory impact analysis; zero waste regimes; and recycling-oriented societies (Ghisellini et al., 2016; Zhijun and Nailing, 2007).

CE is therefore here considered as: a) an integrative concept for attaining "clean congruence" by guiding new institutional set-ups that match environmental considerations with socio-economic performance while promoting techno-economic development that is not depending on the consumption of finite resources; b) a multi-level framework (micro, meso and macro) that re-shapes and re-directs production and business models toward resilience and sustainability; c) an encompassing notion calling for specific actions towards the minimisation of resource extraction, maximisation of reuse, increased efficiency, enhanced waste recycling and the development of new business models.

2.5. Eco-innovation and the circular economy: linking the concepts

If cheap resources for widening markets supported the 20th century's economic growth, the first decades of the 21st century brought rising price volatility and geo-economic uncertainty (Dobbs et al., 2011). Meanwhile, even if recycling is now seen as indispensable, waste production remains largely unchecked (WWF, 2014). Palliatives may not be enough, as global consumption has been increasing dramatically in the last two centuries and is expected to triple by 2050 (Vanner et al., 2014). New global trends are emerging, such as tighter environmental standards and consumer sensitivity to climate change. In this context, the concept of a new economic model, working in closed-loops, encouraging and encouraged by innovation throughout the whole value chain is advocated as an alternative solution for minimising waste of materials and energy in a world that remains competitive and dynamic, but finite (Potočnik, 2014; UNEP, 2006, 2011).

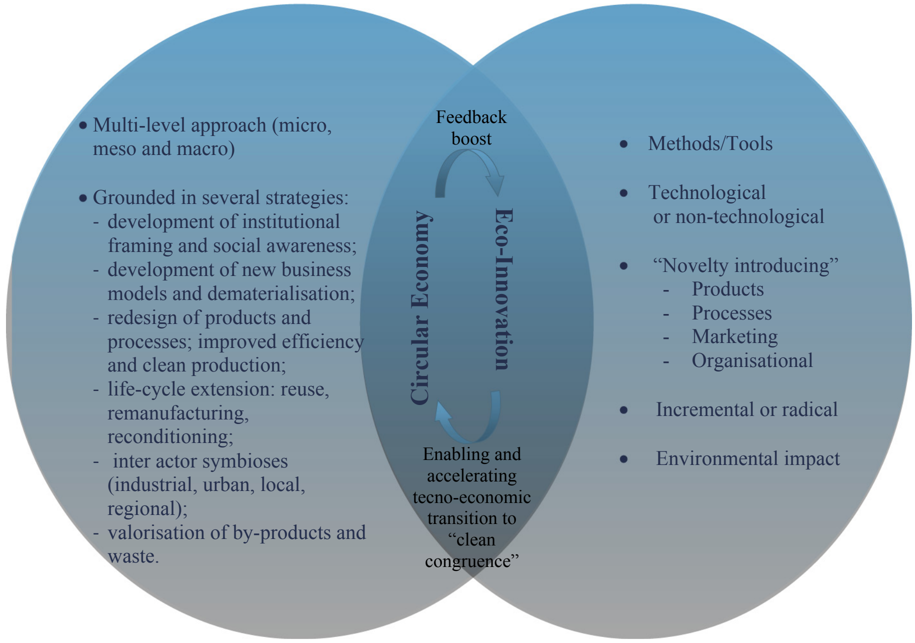

Fig. 1. Relationships between EI and the CE.

The EU, since the adoption of the Lisbon Strategy in 2000, has been actively involved in the development and implementation of a "greener" sustainable economy and society, assuming a global leadership role in this regard. Its most recent efforts concerning the promotion of a transition to sustainability have focused on a number of flagship projects and action plans concerning EI (EC, 2011a; EIO, 2011, 2013), resource efficiency (EC, 2011c; 2014) and, most recently, the CE (EC, 2015). The pursuit of a CE is now central within the EU agenda, with the Commission's Circular Economy Action Plan stressing the EU's commitment and support for CE, but also recognising the close connection with innovation, and especially EI (EC, 2017). It is thus now argued that the CE is contingent "(…) on adopting a systemic approach to eco-innovation that encompasses value and supply chains in their entirety and engages all actors involved in such chains" (EC, 2016, p. 73).

Transforming production routines and consumption habits through an endless rewiring of loose ends of various activities is a dynamic enterprise (EMF, 2013, 2012). EI is identified as a key way for doing so, through the development of new products and processes based on new technologies, as well as new business models, based on novel organisational forms and marketing schemes (Tregner-Mlinaric and Repo, 2014). EI-CE connections, the key focus of this study, can thus be explored (see Fig. 1).

The connections between these two concepts are, nevertheless, complex. Both still encompass several related terms and have somewhat vague boundaries. Even if one can intuitively argue that EI and CE are closely related, and assume that achieving CE without EI is unlikely, it remains to be seen in what ways this is so. Not all EI is related to the CE, and EI might also have different impacts in several areas of the CE. While their relation is undeniable, a deeper analysis could make use of the specific aspects already pointed out, namely EI *targets*, *mechanisms* and *impacts* (horizontal axis) and the *micro*, *meso* and *macro* levels of CE (vertical axis). Fig. 2 brings these categories together so as to explore the *dimensions* of EI (horizontal axis) for each *level* of the CE (vertical axis). The ensuing literature review provides supportive evidence, whilst distilling the practical insights. A deeper understanding of the overlap between EI and the CE may help to articulate how a closed-loop, production-utilisation congruence requires thorough implementation of specific types of change. These self-reinforcing patterns (that can be understood as forms of "clean congruence") can be attained at distinct levels (macro-meso-micro), which may be mapped and monitored as policy, and other decision makers, seek strategies for transition toward a CE. The generic term of "clean congruence" refers to the process of dealing with mismatches at a variety of levels between ecological and economic sustainability in the context of an emerging (green, innovative) techno-economic paradigm.

3. Methodological approach

This paper assumes that it is an appropriate time for investigating the overlap between different streams of research that converge on transition-driven innovation. A literature review, following and adapting several prior methodological contributions (Bocken et al., 2014; Boons et al., 2011; de Jesus and Mendonça, 2018; Khan et al., 2003; Patala et al., 2014), can help the development of concepts linking the converging clusters of ideas broadly understood as EI and the CE.

3.1. Data criteria and collection

Data was obtained from scholarly peer-reviewed journals. A circumscribed corpus was identified by using two of the most widely-used databases of academic journals, namely the Web of Science (WoS) Core Collection[1] and Scopus.[2] Material was

[1] The WoS TM Core Collection is contained within the Web of Knowledge database platform of bibliographic references, produced by the Institute for Scientific Information (ISI), covering over 12,000 of the highest impact journals worldwide in the fields of sciences, social sciences, arts, and humanities, including Open Access journals and over 150,000 conference proceedings, being one of the most generally acknowledged sources of data for bibliometric studies (Franceschet, 2009; Moya-Anegón et al., 2007).

[2] Scopus is the largest abstract and citation database indexing the greatest number of peer-reviewed journals (Falagas et al., 2008), around 21,500, from more than 5000 international publishers (Elsevier, 2014), having a more European focus (Chappin and Ligtvoet, 2014).

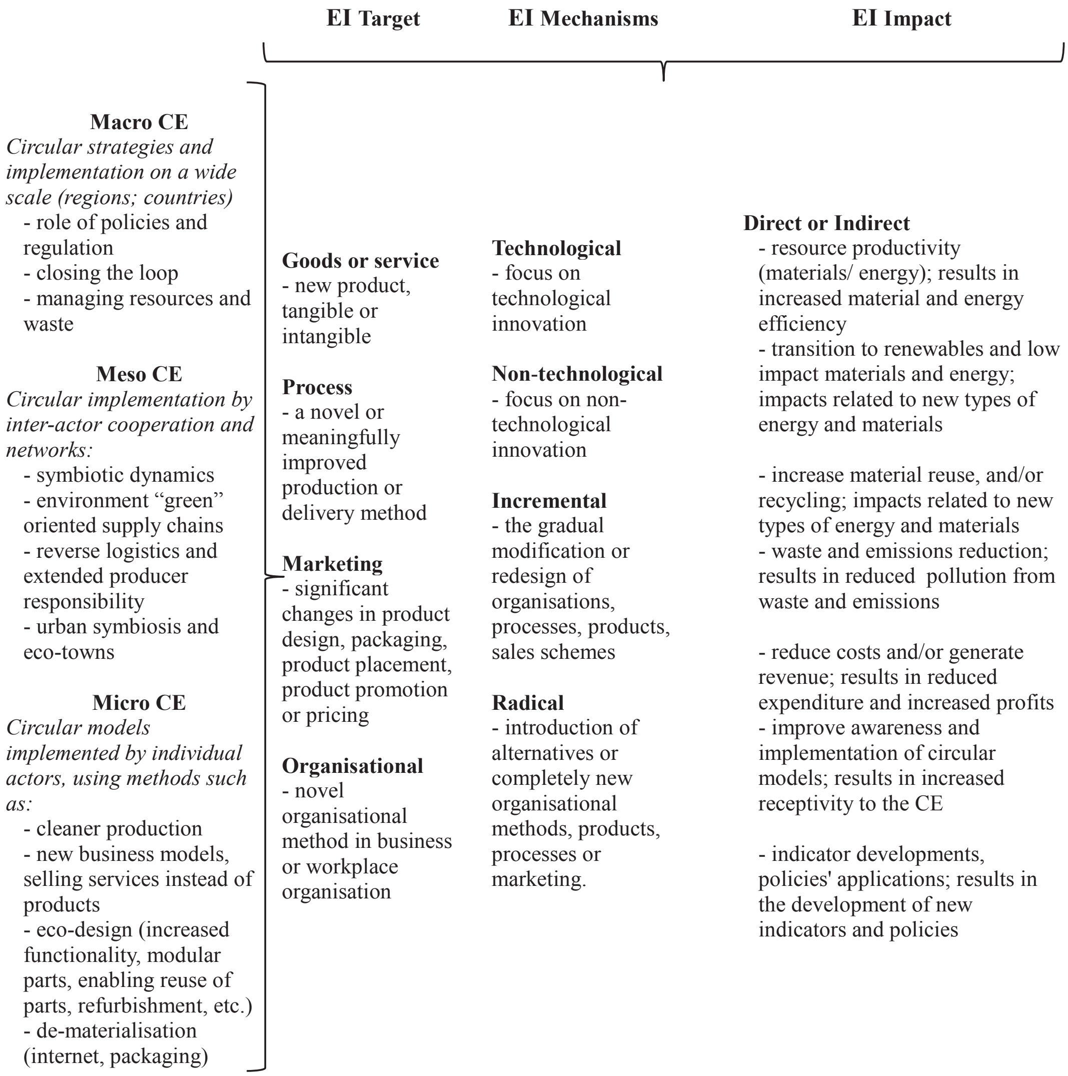

Fig. 2. Levels of the CE and dimensions of EI.
Source - Elaborated from several contributions (Geng et al., 2012; Geng and Doberstein, 2008; OECD, 2010; OECD/Eurostat, 2005)

identified through a keyword Boolean search on title, abstract, and keywords of articles and reviews, written in English, in the assumption that this would identify all the latest relevant global research. The goal was to ensure that relevant peer-reviewed publications were found. As the interconnections between EI and the CE are still not clearly defined, it was acknowledged, from the onset, that the use of the target terms alone carried a risk of exclusion and bias. As section 2 stated, there are several concepts closely connected to EI and the CE. Which ones should then be chosen as keywords, and which ones excluded?

In an initial exploratory exercise, in order to minimize the biases of subjectively choosing a closely connected concept over another, the first query searched only: "*innovat*" AND ("circular economy" OR "circular-economy" OR "circul* economy*").[3] This search identified a total of 21 downloadable articles across the two databases (several articles appeared in both databases and were only counted once). Although this effort produced a very limited set of results, the articles enabled the identification of 86 unique keywords (provided by the authors of the articles). As keywords contain critical and concise information regarding the substance of each article, they were used as guidance for finding other relevant works. By analysing keywords used at least twice, the descriptors "industrial symbiosis", "industrial ecology", "urban symbiosis" and "eco-industrial park" were highlighted. These new descriptors were then used, in association with "*innov*", resulting in the retrieval of an additional set of documents (120 new articles). A grand total of 141 articles, published between 1992 and 2015, were thus assembled as the final corpus for analysis. Fig. 3 illustrates the path followed.

3.2. Analysing the articles

Drawing on the propositions underpinning the EI and CE bodies of research (section 2), the articles were analysed and read in full aiming to identify EI dimensions (i.e. *target*, *mechanisms* and *impact*) per levels of the CE (i.e. *micro*, *meso*, *macro*). These

[3] The search was carried out on 27 March 2015, and then updated on 13 November 2015. For a further exploration of a part of the corpus, concentrating explicitly on drivers and barriers of pro-CE eco-innovation, see Jesus and Mendonça, 2018. The Boolean operator * is used to enable the return of expressions that begin with the word truncated by the asterisk.

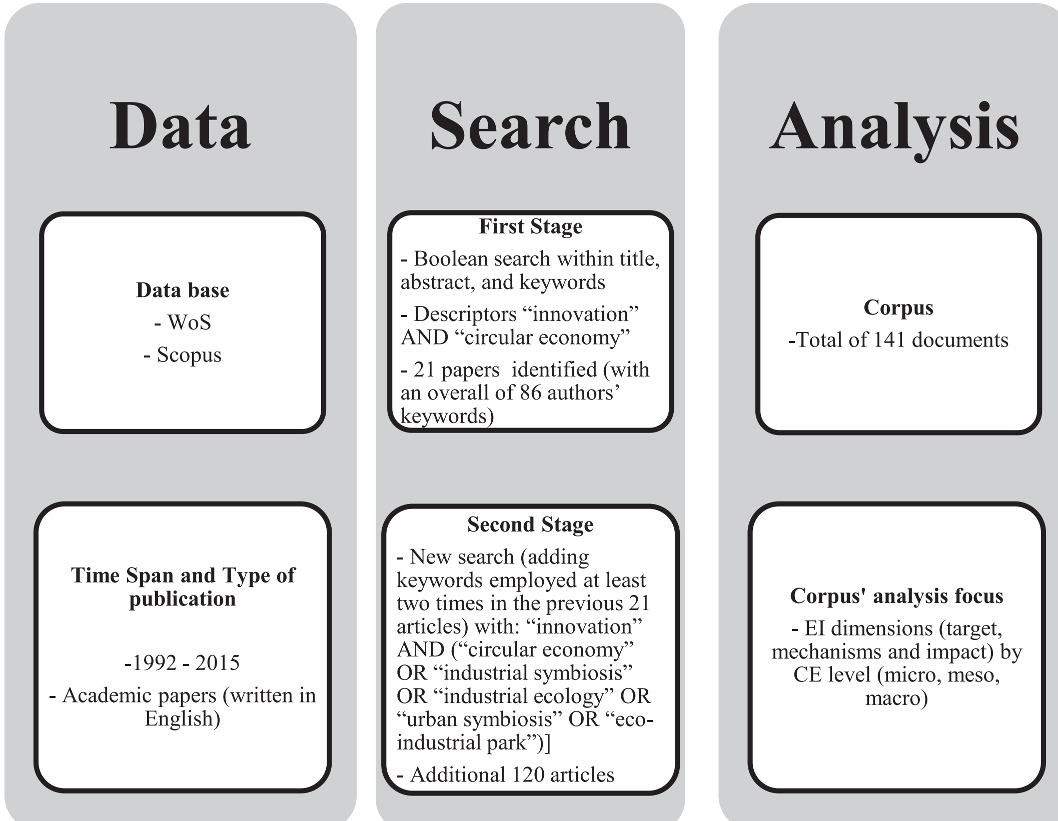

Fig. 3. Layout of the research design.

categories (summarised in Fig. 2), are used to organise the extraction of meaning and trends from the 141 papers.

Categorisations are not straightforward, and their application requires judgement. Regarding EI impacts, for instance, the available literature stresses the difficulty of outlining and measuring it accurately (OECD, 2010). As such, inspired by examples identified in the corpus itself, some EI impacts are typified (Table 4). Here too it was necessary to make choices. Although the impacts are normally divided in the literature by their direct or indirect effects, the types identified could often have both effects. For instance, increased reuse and/or recycling of materials has a direct impact, in terms of reducing pollution and waste production, but may also have an indirect impact, in terms of improving awareness and implementation of CE models.

As for the CE, several of the articles could fall under more than one level of "circularity". For example, cleaner production at a company – the micro level –, when addressed from a government perspective (i.e. fostering the implementation of those initiatives), could be seen as macro level (Geng et al., 2010b). Similarly, as regards eco-towns and urban symbiosis, although other articles usually place these at the macro level (Ghisellini et al., 2016), it was here judged to be better to identify these as meso level, emphasising the cooperation between the city and other actors. As such, choices had to be made when allocating articles to a unique category. The overall goal of the analysis, however, is not to gather exhaustive examples, or to carry out a definitive analysis, but rather to convey the core thinking behind the demonstrative cases, and highlight the major patterns that can be gleaned from the literature, so as to enable the emergence of new conclusions regarding the poorly understood connection between EI and the CE. The inescapable degree of subjectivity involved in implementing the survey criteria was not, therefore, viewed as overly problematic.

4. Eco-innovating towards a circular economy: results of the literature review

In an aggregated overview of the articles it was found that most were published between 2006 and 2015 (83%),[4] which shows that there is a growing interest in these fields (Fig. 4). Using the operational definitions, and the proposed analytical framework, the corpus was examined by CE level, focusing on the role of EI. The macro/meso/micro organising principle for unpacking EI-CE connections allows us to give structure to the findings. The aim was to identify developments in the literature, as well as research gaps and policy prospects.

4.1. CE at the macro level

Examining the sub-set of articles categorised at the macro level, four important considerations stand out: 1) the CE emerges as a multidisciplinary, difficult to define, concept; 2) governance and public policies have a central role in supporting and promoting EI and the CE; 3) at the wider national and transnational scales, resource efficiency and waste management are particular concerns; 4) EI appears to be an enabler of the transition to a CE.

CE is indeed characterised as a wide-ranging concept, still rather difficult to define: "circular economy does not have a single

[4] As the search was updated the 10th September 2015 this can justify the apparent drop in 2015.

Table 4
Key characteristics of EI impacts.

Direct and indirect impacts	Description of impacts
Resource productivity (materials/ energy)	Material and energy efficiency
Transition to renewables and low impact materials and energy	New types of energy sources and materials
Increase material reuse, and/or recycling	Durability and valorisation
Waste/ pollution/ emissions reduction	Lessening of pollution, waste and emissions generation
Reduce costs and or generate revenue	Expenditure reduction or profit generation
Improve awareness and implementation of circular models	Circular models acceptance
Indicator developments, policies' applications	Development of indicators and policies

Source: Elaborations on the corpus.

definition, it generally stresses closed flows of materials, and increased efficiency in the use of raw materials and energy" (Matus et al., 2012, p. 194). Contributions from several different schools of thought add to its intellectual development, from industrial ecology, systems theory, global environment studies, environmental innovation, spatial planning, societal transitions, ecological modernisation, technology policy, and innovation management.[5] The links of CE to a diverse economics background are also evident, being associated with fields such as evolutionary economics and ecological economics - i.e. heterodox research programmes (del Río et al., 2010; Koenig and Cantlon, 1999; van den Bergh, 2013), as well as environmental economics - i.e. more mainstream approaches to the environmental agenda (Su et al., 2013).

At this level another issue raised was the important role of governments in: providing context; ensuring coordination, and; leading the way in the promotion of new industrialisation models that are more efficient, less polluting and involve less exploitation of resources. Progress in science, technology and innovation is identified as a way for developing countries to advance their overall catch-up process (since they have the potential to leapfrog, at least in the environmental-economic nexus), and also a way for developed countries to increase well-being and reduce vulnerability to resource price shocks (Cheng, 2007; Geng et al., 2009b, 2012). Governmental action is, therefore, considered fundamental in managing "different initiatives, enacting appropriate regulations, stipulating feasible guidelines and standards, providing substantial financial support and carrying out international collaboration" (Geng et al., 2010b, p. 1507). Governmental action emerges as both an instrumental driver, in framing pro-CE behaviour and transition-friendly networking capabilities, as well as a barrier, when failing to "enable" a CE context.[6] Since a CE remains a concept under construction, misunderstandings and misaligned policies are possible. Regulatory frameworks (i.e. taxes and incentives) must provide clear objectives in terms of environmental performance, helping to address market failures and allowing CE initiatives to prosper. At the same time, public agencies play a crucial role in ensuring planning and institutional guidance (for example, infrastructure provision and a conducive legal system), as well as by providing R&D support, enabling information exchange, encouraging the engagement of actors and promoting awareness, e.g. amongst enterprises, universities and wider society (Cheng, 2007; Nguyen and Ye, 2015).

In the promotion of a CE, several countries have already acted at a policy level, promoting legislation with CE effects, for instance the

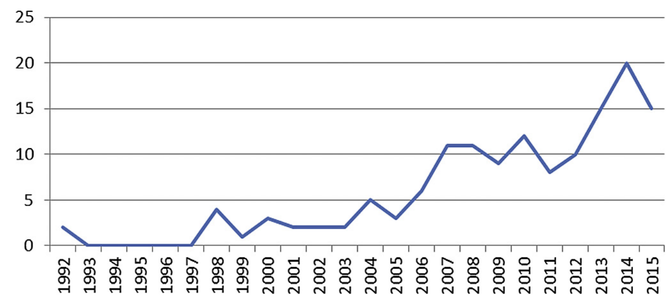

Fig. 4. Number of academic published papers per year.
Source - Elaborations on the corpus; applies to all tables and figures from now on, unless otherwise stated. **Note** - N = 141.

EU action plan for a CE (EC, 2015). Asian countries have also demonstrated an awareness of the CE agenda, particularly Japan and China. The latter was a pioneer of explicit legislation regarding CE (Dong et al., 2013b), making it a key national policy and a regulatory priority, in particular as a vector for focusing on cleaner production and eco-industrial parks development (the *12th Five-Year Plan*, 2011–15).

Emerging policy avenues have underlined the need to move away from the existent resource-based paradigm. As consumption has risen, in both developed and developing countries, recycling and reuse has been identified as vital in closing the loop (Graedel and Cao, 2010). This transformation is considered dependent on innovative technologies, as well as new organisational forms, to manage resources and waste (Geng et al., 2014; Giannetti et al., 2004; Zhijun and Nailing, 2007). Awareness of the intrinsic value of waste and "the extent of knowledge that (…) led to technological innovation for reuse" (Park and Chertow, 2014, p. 47) has become essential. If throughout human history waste has been recognised in a negative sense (associated with unwanted, unusable, worthless materials, lacking economic value or potential), current challenges reinforce the need for a rethink. In a CE waste is meant to be minimised (Köhler et al., 2011; Levänen, 2015) and rather returned as an available resource[7] in a process that is efficiently macro-managed in order to guarantee further community development. The need for novel management practices in the production process is stressed, i.e. production needs to be organised more broadly, so that it transcends the linear input-to-output sequence (Jones et al., 2013).

Technology-driven EI is considered as an enabler of new ways of reusing and recycling substances, giving them other industrial applications (Wen et al., 2007). However, the CE is more than just about re-engineering existing processes (i.e. incremental change of existing components); importantly, it is also about re-wiring (i.e.

[5] To enable easier reading, when there are more than three references together these are gathered in footnotes, here: (Baas and Hjelm, 2015; Bakshi et al., 2015; Cohen, 2006; Deutz, 2009; Huber, 2000; Koenig and Cantlon, 1999; Körhönen et al., 2004; Körhönen, 2008; van den Bergh, 2013).

[6] (Andrews and DeVault, 2009; Bergquist et al., 2013; Cheng, 2007; Heyes and Kapur, 2011; Yarime, 2007).

[7] (Birat, 2015; Corder et al., 2015; Fichter and Hintemann, 2014; Muñoz et al., 2008).

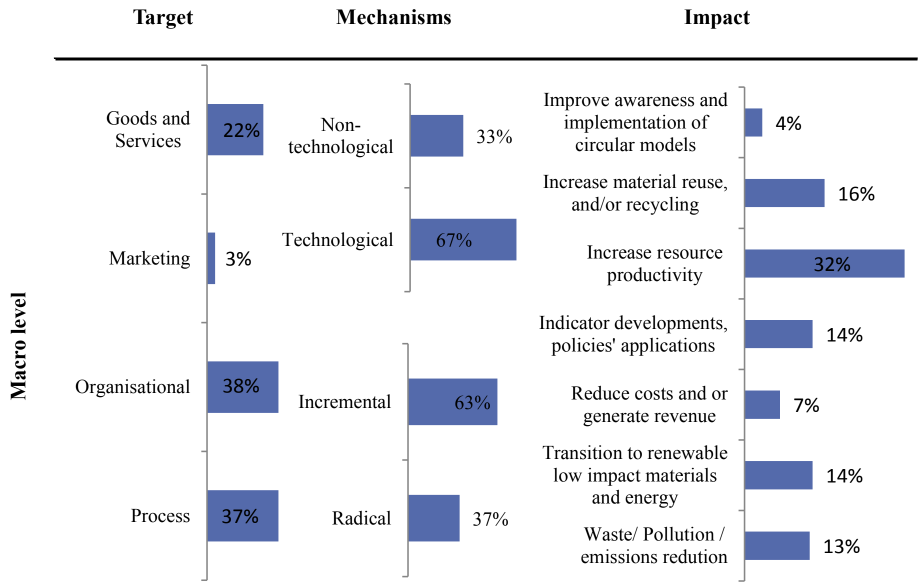

Fig. 5. EI Target, Mechanism and Impact at the CE Macro level, analysis of the corpus. **Note** - N = 80.

changing the architecture of) the whole system of supply and demand. More cost-effective, less environmentally-harmful innovations hinge upon the creation of realistic market opportunities (Brils et al., 2014), as well as the design of new processes and products,[8] while information and communication technologies are crucial in product/service "dematerialisation", product tractability and performance monitoring (Erdmann and Hilty, 2010; Maurizio Catulli, 2012; Moreno et al., 2011). Given its role in decreasing the environmental impact of economic activities, EI is understood as a major new avenue for introducing systemic novelty in the transition towards more sustainable and viable counties, within an integrated vision of society, economy and environment.[9] Overall, process and organisational innovations are the types of EI more emphasised at the macro level (Fig. 5). Technological EI emerges as critical, mostly in the form of incremental mechanisms based on the redesign of existing products and production methods, focusing particularly on increasing resource productivity (see Fig. 5).

Macro-level "circular" EI, however, is also characterised by mixed environmental results (Vivanco et al., 2014). There are rebound effects. For instance, low carbon technologies use rare materials, such as lithium. The availability of these materials can become an environmental and procurement problem for nations and regions. With regard to the UK electric vehicles market, Busch et al. (2014) provide an example that material flows should be holistically managed so as to avoid constraining the long-term potential for improving the reuse, re-manufacture and recycling of the materials involved. EI is also hampered by: high initial costs (Busch et al., 2014; Mirabella et al., 2014; Reh, 2013); limited public and business awareness (Heiskanen and Lovio, 2010; Jones et al., 2013; Riding et al., 2015), and potentially; regulatory mismatches and conflicting interests between economic and environmental agendas.[10]

Similarly, and in spite of playing an important role, science and technology *per se* (i.e. EI disconnected from the broader context) are not considered sufficient conditions for the transition to new paradigms. Whereas technological innovation is believed essential for boosting resource efficiency, as well as production and waste minimisation, non-technological innovation is still deemed essential for "selling" new products and services (Dewick et al., 2007). A systematic approach to change, addressing the societal and contextual settings, is thus highlighted as crucial (Huesemann and Huesemann, 2007). More than revolutionising the existing economic structure, the EI mechanisms stressed at the macro level focus on evolutionary changes towards a "clean congruence", based on incremental redesign and modification of existing systems spanning different sectors and value chains. This seems compatible with the development phase of a CE when several products, industries and business models are emerging (Blowfield and Johnson, 2013). Within this transition, the emergence of new technologies is complementary to wider social, economic and legal/political developments, including increased public awareness, new regulations, and changes in market supply and demand. At a macro level, this phase can be characterised as a temporary period of reorganisation and reconfiguration of a country's techno-economic systems, involving all societal actors.

4.2. CE at the meso level

The meso level addresses networks and interactions. Moreover, CE's own nature, as an integrative multi-actor approach, points to the importance of networks for: building capacity; increasing cooperation in research and investment; sharing materials and by-products, and; managing common utilities and infrastructures. The establishment of these networks is generally motivated by agents interested in cost reduction, economies of scale, and lesser exposure to resource price volatility, and is a determining factor in the implementation of a truly CE. At a meso level, the CE links with several concepts related to the establishment of cooperation and alliances, from which the corpus emphasises those in or within: industry (e.g. industrial symbiosis and eco-industrial parks); value chains (e.g. sustainable, environmental and "green" supply chains,

[8] (Anastas and Lankey, 2000; Barberio et al., 2010; Fiksel, 2002; Grundmann et al., 2013; Jin et al., 2004; Matus et al., 2012; Ogunseitan, 2007; Reh, 2013; Thomas et al., 2003; Wen et al., 2007).

[9] (Carrillo-Hermosilla et al., 2010; Cheng, 2007; del Río et al., 2010; Ganapathy et al., 2014; Tombesi, 2006).

[10] (Busch et al., 2014; Jones et al., 2013; Matus et al., 2012; Riding et al., 2015).

and extended producer responsibility); local-government initiatives (e.g. eco-towns and urban symbiosis). The emphasis given to these concepts, rather than others, may be related to the scope of the corpus itself, covering largely European and Asian examples.

Industrial symbiosis is based on an "industrial systems integration" approach (Geng et al., 2014). It focuses on the potential of networks for exchanging materials and by-products, as well as for sharing management of common utilities and infrastructure for water, energy and waste, between several actors (van Berkel et al., 2009). The sharing of services, such as transportation and infrastructure, and the brokering of by-products (so that the waste from one industry waste becomes the input of another), results in pollution mitigation, decreased use of materials and energy, and cost reductions, and thus creates both economic and environmental benefits. Kalundborg in Denmark is considered the pioneer model and inspiration, but there are already several other examples of industrial symbiosis.[11] Linked with industrial symbiosis, the notion of an eco-industrial park is also important. Eco-industrial parks retain the positive externalities of industrial parks, which arise from: businesses being located close together; economies of scale; inter-firm communication; centralised transportation, and; waste disposal infrastructure. However, they also add the potential for symbiosis regarding ecological considerations, related to minimising negative impacts in local resource depletion and pollution. In spite of geographical peculiarities (given that the definition and implementation of industrial symbiosis and eco-industrial parks can differ from country to country) (Boons et al., 2011) and varying stages of development (Chertow and Ehrenfeld, 2012), eco-industrial parks have been found to foster symbiotic networks of cooperation between enterprises (Yu et al., 2015), thus actively promoting the CE at an industrial level (Zhu et al., 2015). For instance, at TEDA – Tianjin Economic-Technological Development Area (China) – the integration of the regional water cycle system provided recycled water to all of the area's users, demonstrating the potential of symbiotic relationships within the eco-industrial park (Yu et al., 2014). EI is considered essential in the development of eco-industrial parks and industrial symbiosis, whilst, at the same time, these concepts have a role in the development of institutional, technological and business model innovations (Shi and Yu, 2014).

As for "sustainable supply chain management" (Gupta and Palsule-Desai, 2011; Ji et al., 2014; Zhu et al., 2010), "green supply chain" management (Mirhedayatian et al., 2014; Park et al., 2010), "closed-loop supply chain" management (Guide and van Wassenhove, 2009), extended supply chain (Zhu and Geng, 2013), and "extended producer responsibility" (Chen and Sheu, 2013; Lai et al., 2014), these concepts all focus on improving a product life-cycle via its supply chain. The objective is to reduce costs by sustainably managing the life-cycle of products from conception (e.g. less use of materials and energy in production, packaging and delivery) to end-of-life (e.g. reuse, reduced waste, creating recovery networks etc.). This involves the responsible incorporation of environmental considerations into supply chains from the outset, and the promotion of cooperation between companies, suppliers and customers, to "close the loop". The conversion of existing supply chains is supported by a set of technological developments that enhance resource efficiency, reuse and recycle, as well as organisational innovation leading to new distribution, collection and business models (Rashid et al., 2013).

Considering that urban growth is accelerating, especially in developing countries, and that cities play a role as both industrial and population centres, an integrated approach to cities is necessary for designing new ways of tackling environmental problems and mitigating pollution (Dienst et al., 2013). In China, in particular, the problems of the so-called "resource-based cities" (i.e. cities primarily orientated towards extractive and/or resource-intensive industries) have drawn attention given the importance of integrative strategies for moving towards more "circular" cities (Dong et al., 2013a). In this regard, the concepts of urban symbiosis and eco-towns have extended the network rationale to urban actors. This is an integrated view of urban infrastructure, maximising benefits arising from the interrelation between the city and its industrial context, as well as the possibilities within the city itself for fully capitalising on reinforcing infrastructural use, rather than duplicating resources.[12] In this domain, an innovation-friendly environment, as well as efforts from several actors (including governments and companies), are important factors in the development of low-carbon cities (Dong et al., 2013a). Innovation in these processes involves enhancing the ability to develop both "software projects" (e.g. town planning, community recycling, and outreach activities) and "hardware projects" (e.g. innovative recycling facilities and associated infrastructure) (Chen et al., 2012).

Closing the loop at the meso level therefore seems dominated by inter- and cross-sectoral pooling of infrastructural resources (i.e. eliminating wastage in overhead capital), as well as by the maximisation of synergies across different value chains (i.e. interactions between production systems and agents). Promoting cooperation and interrelations between geographically-close actors, companies and organisations, is considered an effective way of achieving a more circular system, with better use/reuse of resources. It seems interesting to note that, in regard to these relationships, the role of business associations is never mentioned in the corpus, while one could expect these and other entities (such as consumer organisations) to play a role in bringing companies together, so as to increase collective environmental efficiency.[13]

Overall, EI at the meso level is described as a facilitator of sectorial or regional systemic integration, enabling new ways of sharing services, utilities and by-products, which in turn provides new ways of promoting cooperation.[14] Green and transformative innovation is key for engaging in financial engineering (i.e. responding to high initial costs and capital investments), as well as for identifying symbiotic links between organisations and sectors (i.e. synergies), and for addressing technical issues such as solid waste, air pollution, water contamination and noise pollution (i.e. bottlenecks for transition).[15]

At this level the literature points to the importance of this green and transformative innovation in attaining a "clean congruence" mostly based on the organisational dimension, on incremental mechanisms (redesign of organisations and processes is particularly stressed in the articles) and on targeting resource efficiency, material reuse and recycling (Fig. 6). The transition toward CE seems therefore plough on "green collective innovation"

[11] (Chertow and Ehrenfeld, 2012; Geng et al., 2009a; Liu et al., 2012; Mathews and Tan, 2011; Park et al., 2008; Patnaik and Poyyamoli, 2015; Shi et al., 2010; Shi and Yu, 2014; Yu et al., 2014; Zhu et al., 2015).

[12] (Chen et al., 2012; Dong et al., 2013a, 2014; Geng et al., 2010a; Niza et al., 2009; van Berkel et al., 2009).

[13] The general role of such intermediate associations in the innovation process has been emphasised in a small amount of relevant literature (see, e.g., Dalziel, 2006; and Watkins et al., 2015).

[14] (Baas, 2011; Bristow and Wells, 2005; Desrochers, 2004; Dong et al., 2014; Gupta and Palsule-Desai, 2011; Killerby et al., 2007; Lombardi and Laybourn, 2012, 2012; Mirata and Emtairah, 2005; Paquin and Howard-Grenville, 2012; Park et al., 2008; Ruiz Puente et al., 2015; Short et al., 2014; Simboli et al., 2014; Watkins et al., 2013; Yu et al., 2015; Zhu et al., 2010).

[15] (Cecelja et al., 2015; Geng et al., 2009a; Hewes and Lyons, 2008; Liu et al., 2012; Mathews and Tan, 2011; Park et al., 2008, 2008; Patnaik and Poyyamoli, 2015; Raafat et al., 2012, 2013; Shi et al., 2010; Shi and Yu, 2014; Sterr and Ott, 2004; van Berkel et al., 2009; Yu et al., 2014; Zhu et al., 2015).

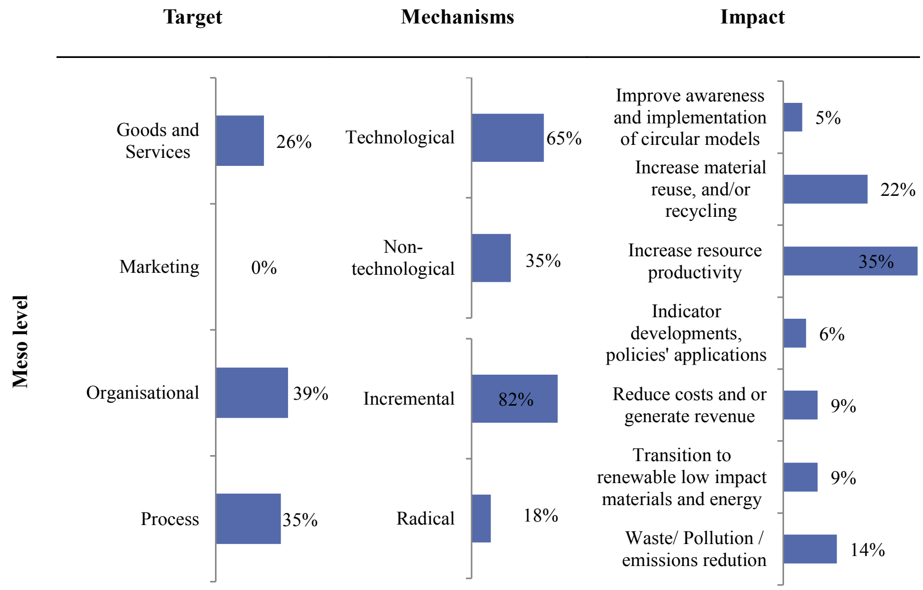

Fig. 6. EI Target, Mechanism and Impact at the CE Meso level, analysis of the corpus. Note: n = 43.

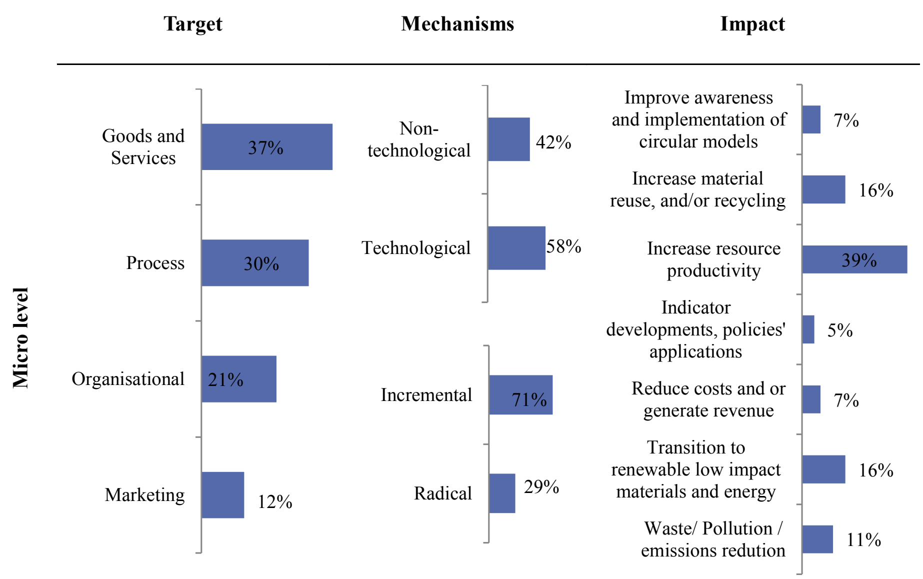

Fig. 7. EI Target, Mechanism and impact at the CE Micro level, analysis of the corpus. **Note** - N = 18.

trajectories as a way to achieve “clean congruence” at the meso level.

4.3. CE at the micro level

The micro level focuses on specific agents' capabilities and involvement in CE. It comprises, nevertheless, the smallest part of the corpus, which was a surprise. Although this result could indicate an area of research that is still on its way to maturity, it may also be a sign of a methodological shortcoming. First, it may be that the most appropriate keywords for the micro level were not used; second, and more important, it may be that innovation at this level is very specific and unlikely to be published within scientific articles (patent data could be more revealing in this respect, for instance, something interesting but not pursued in Silva and Mendonça in UN, 2015). Within the corpus, this body of work focuses particularly on cleaner production, eco-efficiency, eco-design and new business models.

Cleaner production emphasises the application of processes, technologies and practices for minimising resource and energy consumption, as well as pollution, in order to accomplish a better overall efficiency within the organisation (Geng et al., 2010b). It includes green design as well as the introduction of clean energy and waste management technologies (Basu and van Zyl, 2006). Other practices such as eco-efficiency (i.e. production of goods or services with fewer resources and waste), and eco-design (i.e. design for the environment), similarly aim to design products with environmental considerations throughout their whole life-cycle, thus ensuring energy savings and pollution reduction.[16] The literature cites practical examples ranging from the conservation of

[16] (Collado-Ruiz and Ostad-Ahmad-Ghorabi, 2013; Matos and Hall, 2007; Mattinen et al., 2015; Mont, 2008; Sanyé-Mengual et al., 2014).

resources (Silva et al., 2015), to product design focusing on life-cycle aspects regarding materials usage, processing and maintenance, as well as communication with end-users (Sanyé-Mengual et al., 2014).

New business models based on leasing, rental and "sharing" services, also emerge in this literature, focusing on the replacement of capital ownership and proprietary models. In areas as diverse as housing, transportation and communication, these business models promise more efficient use of resources, extended lifespan of products, and greater reuse of materials at the end-of-life of products (Albu, 2011; Short et al., 2014).

At the micro level, the EI of goods and services is particularly stressed, especially in an incremental mode, in terms of both increasing resource efficiency (Adams and Ghaly, 2007) and eco-design (Cerón-Palma et al., 2012; Sanyé-Mengual et al., 2014). Nonetheless, radical alterations are also believed to be necessary as the transition to new sustainable ways of living implies the genuine transformation of the *status quo* (Fig. 7).

Technological EI mechanisms are established as tools for addressing bottlenecks in product durability and quality, in designing goods with longer usability spans, and addressing problems of decreasing efficiency over time (Adams and Ghaly, 2007; Mattinen et al., 2015). Designing optimal product life scenarios requires an in-depth knowledge of durability and the replacement schedule of parts. However, it also creates the possibility of constant upgrades (Bakker et al., 2014). Alternative, less expensive ways of reusing and re-manufacturing products are indispensable, since the costs of re-manufacturing are still often higher than the costs of production using virgin materials. Likewise, new ways of limiting the extra (economic and environmental) transportation costs involved in product reuse and re-manufacturing, are essential in order to make these activities more viable (Mont, 2008). But, even if the technology already exists, other kind of innovations may be needed to overcome several reasons that often prevent more sustainable designs. Consumers are still mostly unaware of the choices available (Finster et al., 2001). The lack of transparency and credibility coming from dissatisfaction with empty greenwashing rhetoric also hampers the development of "green markets" and the willingness of customers to pay for "green" goods and services (Lemke and Luzio, 2014).

Non-technological EI, promoting new organisational models may support new schemes for increasing product use intensity through sharing and pooling. At the same time, marketing innovations can enable new ways of distribution, usage and perception for products and services - e.g. monthly payments for the use of refrigerators, washing machines, concrete mixers, and other tools such as drills, saws, hammers etc. (Bakker et al., 2014; Ceschin, 2013; Mont, 2008). These softer type of innovation trends may create incentives for producers to: develop longer-lasting products; replace existing products with more efficient models; and even to upgrade already existing products when new technology becomes available (Mont, 2008). The role of marketing innovation is rather unexplored in the corpus. Similarly, the role of consumers as innovative agents is also not much addressed. This seems paradoxical, since consumers are an integral part of a CE, not only as demand-side actors, but also as an active part of global supply chains themselves.[17] Hence, "dynamic CE business models" seem to be of the essence at the micro-level as a ways to operationalise "clean congruence" and enable transition.

[17] The work on user-driven innovation is very relevant here (see, e.g. Von Hippel, 2005), and could have many applications in the area of EI and the CE.

4.4. *Clearing the ground for "clean congruence": exploring the meaning and implication of EI-CE connections*

The assembled corpus of articles enables some considerations about the main objectives of this paper: 1) to derive literature-based working definitions and links between the EI and CE concepts; 2) to review and assess the relation between EI and CE's various levels, and; 3) to identify the types of EI which are most influential in driving the transition to a CE.

First, the definitional challenge is not a minor one. The CE concept suffers from vague boundaries and it includes inputs from several schools of thought (Matus et al., 2012). Several slightly different definitions, linking innovation to environmental questions, have also been proposed in the last few decades (Carrillo-Hermosilla et al., 2010). Although the latitude still present in the studies on EI and CE enables the integration of several strategies and perspectives under increasingly used labels, it may hinder their development and hollow out their meaning. Tentative definitions of CE and EI are thus required, which aid the development and use of both concepts; a need this paper addressed by proposing working definitions for both CE and EI.

As a broad framework, the relationship between CE and the notion of innovation is still not obvious. CE is an integrative multi-actor approach in which EI (technological and non-technological based) is a tool in the transition towards a cleaner form of "congruence" bringing about a new "techno-economic paradigm" (in the sense of Freeman and Louçã, 2001). Some authors focus on CE strategies as drivers for EI: e.g. as a "leading principle for eco-innovation, aiming at 'zero waste' society and economy" (Mirabella et al., 2014, p. 29). However, other authors highlight the causal role of EI within the CE; e.g. "the capacity of eco-innovations to provide new business opportunities and contribute to a transformation towards a sustainable society" (Carrillo-Hermosilla et al., 2010, p. 102).

The inherent relationship between these concepts appears in all the CE levels considered, which we take as pathways or trajectories towards achieving "clean congruence" (introduced here as a bridging concept between EI and CE literature). Moreover, the disaggregation by CE level enabled a more thorough and deeper analysis of the main features of EI. At a macro level, governance has a central role in providing context (Cheng, 2007; Geng et al., 2010b, 2012). By promoting EI-led CE policies related to waste management, infrastructure availability, science and technology improvements and public awareness, the government can be an inspiring actor. Governments may also have a coordination role in the movement towards a "clean congruence" at cross-sectoral and cross-regional levels; i.e. by avoiding wasteful lock-ins and mismatches that may lead to system failures and barriers to transition along broadly interdependent constituencies and value chains. At this level EI refers to the broad self-reinforcing combinations of socio-technological coalescing changes (i.e. "clean congruence") that allow transition to a CE to take place.

At the meso level, CE is considered to be contingent on systemic or transformative EI enabling new ways of "green collective innovation". That is, innovation that is based on multi-actor and multi-expertise comprehensive technological and non-technological (i.e. organisational and process) change. The latter involves creating new ways of sharing services, utilities and by-products, i.e. providing new ways to promote cooperation. This level highlights the importance of public policies and new ways of boosting cooperation between enterprises and public actors, promoting symbiotic links, addressing technical issues and overcoming institutional barriers (Boons et al., 2011; Cecelja et al., 2015; Raafat et al., 2013).

At a micro level, business strategies range from internal actions of cleaner production (in energy and materials efficiency) to the development of new, more circular business models (i.e. service-based user-producer relationships). At this level, the replacement of the "take-make-dispose" business model implies a greater emphasis on new products, servicing, resource pooling and marketing concepts with EI as a tool to address bottlenecks in product durability and quality, in designing efficient products and "dynamic CE business models". The sharing of business models and resource pooling schemes are emphasised, as they are especially dependent on pricing innovations and networking-empowered behaviours (Albu, 2011; Short et al., 2014). However, the role of users and citizens at large, so essential in a paradigm shift, is not yet really addressed in the corpus. This may point to the fact that, in spite of being essential for "circularity" efforts, these issues are seen as too narrow to be called "circular" *per se*. Research at the micro level is also constrained by the fact that the application of the notion of what a CE-based business concept can mean is still under-developed and in a state of flux.

Finally regarding the most influential types of EI driving the transition to a CE organisational and process EI seem generally well developed (especially at the macro and meso levels), whereas references to marketing innovations are scarce. Regarding EI mechanisms, even if authors do reiterate the need for more radical approaches, incremental EI is still predominant. Technological EI, in particular, is considered to be an enabler of change, and essential in the creation of a CE even if the transition is acknowledged to require more than just science and technology.

5. Key implications of the EI-CE connections

Our review points toward some key themes and main links between EI and CE, which helps to outline broad influential types of EI within specific levels of the CE. These intersections in turn allow a better understanding on how processes of innovation shape transition to a CE and inspire some preliminary considerations regarding policy and business implications. In particular, we relied on constructs such as EI-dimensions and CE-levels to outline how current research is pointing to pockets of "clean congruence", which in turn may provide guidance to policy (summarised in Table 5).

Regarding policy, the link between the CE and EI has been most explicitly addressed in recent years by the EU. Increased connections between the two concepts was apparent in the recent *EU Action Plan for the Circular Economy* (EC, 2015), following the prior resource efficiency agenda (EC, 2011c), as well as in the Eco-Innovation Action Plan (EC, 2011a). Moreover, policy measures related to regulatory and economic instruments are now closer to the policy implications identified in the corpus. These have been emerging in some EU countries, especially in aspects related to research, education and networking. Even if those efforts are not yet widely disseminated, the examples already in place constitute interesting opportunities for acquiring information about the practical application of pro-CE policy at the national and local levels, whilst also highlighting the differences between actors (EIO, 2016). Examples and characteristics, compiled in Table 5 are not

Table 5
Main features from the EI-CE literature, including "pro-CE" EI characteristics, types, and policy and business implications, by CE level.

	Key features from the EI-CE literature	EI role	Major types of CE-inducing EI	Policy and business implications	Examples in the corpus
Macro	At a macro level, EI refers to the broad self-reinforcing combinations of socio-technological coalescing changes (i.e. "clean congruence") that allow transition to a CE to take place.	EI mechanisms focus on evolutionary mutations towards overall "*clean congruence*".	Target/Type:- Organisational;	The importance of explicit public policies and new ways of streamlining cooperation between the public and private sectors.	Carrillo-Hermosilla et al., 2010; Cheng, 2007; del Río et al., 2010; Geng and Doberstein, 2008.
		EI's role as decreasing the environmental impact of economic activities, introducing all-round novelty in the transition towards more sustainable, and integrating vision of society, economy and environment.	Mechanism:- Technological.	Public agencies have a crucial role in planning, providing institutional standards and guidance (infrastructures provision/ conducive legal system). Pro-CE innovation policy is to provide R&D support, but also should facilitate peer-to-peer information exchange.	
Meso	At a meso level, innovativeness for circularity is a distributed and systemic process, where the potential for synergies within value chains and territories are ripe.	EI as a facilitator of systemic integration, enabling new ways of *"green collective innovation"* such as sharing services and other schemes for maximising the value of common resources.	Target/Type:- Organisational;	Promoting the cooperation and interrelation of geographically close companies and organisations is considered to be an effective way of achieving a more circular system, with better use of energy, materials and resources.	Gupta and Palsule-Desai, 2011; Lombardi and Laybourn, 2012; Ruiz Puente et al., 2015; Watkins et al., 2013; Zhu et al., 2010.
		EI is a way to re-direct and re-employ by-products among diverse industrial processes or actors	Mechanism:- Technological.	Strengthened cooperation between actors, and resulting synergies, limits exposure to resource price volatility, reducing costs and minimizing the use of non-recyclable materials.	
Micro	At a micro level, the replacement of the "take-make-dispose" business model implies a greater emphasis on new products, servicing, resource pooling and marketing concepts.	EI as a tool to address bottlenecks in product durability and quality, in designing efficient products and "*dynamic CE business models*".	Target/Type:- Goods and services;	Government role is key regarding the creation of a CE, ensuring adequate regulatory frameworks, and encouraging the awareness of actors and social participation.	Albu, 2011; Bakker et al., 2014; Mont, 2008; Sanyé-Mengual et al., 2014.
			Mechanism:- Technological.	CE considerations may prove to be an opportunity for positive business differentiation, the development of new CE-friendly business models, and increasing resource efficiency.	

Source: Elaborations on the corpus

intended to be exhaustive but rather a testimony of the most "real world" relevance features identified in the corpus. It should be stressed that CE-inducing EI policy and business strategy constitute a fertile ground to be investigated in more depth in the future.

6. Concluding remarks

What is the role of innovation in a sustainable techno-economic paradigm transition? This paper tried to address this question by focusing on the ways "eco-innovation" (EI) promotes a "circular economy" (CE). To clarify the CE-EI link, a corpus of specialised academic literature was identified and reviewed. The research comprehensively covered published peer-reviewed journal articles. By critically and analytically re-using this material, this paper strived to provide new insights regarding the connections between EI and the CE. In doing so it proposed the concept of "clean congruence" as a bridge between the two literature and sought to illuminate the *dimensions* that are more instrumental in achieving a CE at a variety of *levels*.

The overlap between the EI and CE literature is a fertile ground for fine-tuning the definitional issues that still remain open. Based on the literature, this paper advanced working definitions of CE and EI. CE is defined as an approach towards sustainable development achieved through several strategies aiming at: "input minimisation and efficient use of regenerative resources", i.e. material and energy efficiency and focus on renewable and non-hazardous materials; "life cycle extension and systems reconceptualization", designed from the outset for efficiency, reuse, repair, and recycling; "output reduction valorisation and waste minimisation" focused on resource and waste minimisation in production-consumption systems.

EI is defined as a set of technological and non-technological innovations that prevent, mitigate, and allow recovery from environmental damage. Overall, technological EI seems to enjoy wider popularity as a heuristic for the transition to a CE. However, the need to add other dimensions, beyond science and technology, is increasingly being recognised, with "softer" service and marketing innovations becoming emerging issues in the literature.

Regarding the connection between the concepts, the creation of a CE seems to be contingent on a process based on cooperation and multi-actor "systemic" integration, with EI emerging as a pathway for achieving that. The EI-CE research shows the importance of what has been emphasised generally as "clean congruence" at the macro-level, as "green collective innovation" at the meso level and "dynamic CE business models" at the micro level.

The methodological constraints of "meta" studies are the most relevant shortcomings of this paper, particularly related to randomisation and the representativeness of the sample. A literature review using bibliometric considerations implies inherent biases linked with keyword definitions and the limited number of sources (Li and Zhao, 2015). This paper did not collect material from books or reports, for example, in the assumption that journal articles are usually the preferred means for academics and practitioners to publish their newest research (Chappin and Ligtvoet, 2014; Linnenluecke and Griffiths, 2013; Markard et al., 2012). The findings could nevertheless benefit from contextualisation using these wider sources of data, particularly considering recent vibrant CE agendas in several organisations. The identification of search terms also carried implicit risks of exclusion and biases. For instance, the predominance of macro and meso perspectives in the corpus may be attributable to biases in the initial choice of keywords. However it may also be due to still-evolving definitions of CE being mostly focused, so far, on the macro level. These caveats underscore the necessity of critical reflection about the findings, as well as the need for further empirical research. This paper did not aim to exhaustively collect examples, but rather to express the core thinking behind the literature, so as to enable the emergence of new conclusions regarding the connection between CE and EI. Nonetheless, the methodological and database limitations may still be alleviated in future, by expanding the knowledge base from which lessons are drawn.

Finally, this is a dynamic field with a wide range of opportunities for further research. A deeper understanding of the connections between the CE and EI is still elusive, requiring more empirical methods for assessing and measuring their mutual influence, in particular regarding the role of EI in implementing a CE. Moreover, since these concepts have a wide application, the way in which they are used and understood by different stakeholders varies. As a result, a better understanding of these diverse perspectives is needed in order to better tailor strategies and policies. For example, the role of consumers as "part of the supply chain" and "innovative agents" in the development of a CE has not yet been properly addressed.

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