ISCTE Business School
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CIRCULAR ECONOMY AND ECO-INNOVATIONS:

A TAXONOMY OF POLICY INSTRUMENTS

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Dissertation submitted as partial requirement for the degree of

Master of Science Business Administration

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October 2018

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Abstract

Recently, amidst increasingly pressing environmental concerns, the Circular Economy (CE) concept has been defended, by both scholars and practitioners, as an alternative to the 'take-make-dispose' economic paradigm by emulating the naturally occurring, self-renovating cycles. The CE is enabled by and depends on various technological and non-technological eco-innovations (EIs), i.e., innovations that cause a net positive environmental impact. The complex and systemic interrelations and feedback mechanisms implicated have attracted attention to the role of innovation policy in driving EIs. However, the circular economy – eco-innovation – innovation policy nexus is only now beginning to emerge in academic literature and more research is needed to detail the instruments involved and understand their interplay towards promoting an EI-mediated CE transition. In the present work, we analysed data collected through systematic literature review to propose and characterise an evidence-based, goal-oriented taxonomy for policy instruments. Thus, six core categories of policy instruments are explored: 1) R&D increase, 2) Non-financial capabilities, 3) Network capability, 4) Increase demand, 5) Regulations and Standards, and 6) Foresight activities. Our results highlight the complexity underpinning the design of innovation policy mixes. We conclude that an approach that, on one hand, targets the various stages in material cycles and on the other hand, considers policy instrument features and their complementarity seems to benefit the creation of 'circular' innovations and the CE transition.

Keywords: Circular Economy; Eco-Innovation; Innovation Policy; Taxonomy

JEL Classification: O and Q

Resumo

Recentemente, no meio de preocupações ambientais crescentes, o conceito da Economia Circular (EC) tem sido defendido, tanto por académicos como praticantes, como uma alternativa do paradigma económico 'extrair-transformar-descartar' emulando os ciclos naturais de autorregeneração. A EC é incitada por e depende em diversas EI tecnológicas e não-tecnológicas, i.e., inovações que causam um impacto ambiental líquido positivo. As inter-relações complexas e sistémicas e os mecanismos de reforço implicados têm vindo a chamar à atenção para o papel das políticas de inovação na incitação das EIs. No entanto, a conexão entre a economia circular – eco-inovações – políticas de inovação só agora começa a emergir na literatura académica e são necessários mais estudos para detalhar os instrumentos de política envolvidos e compreender os mecanismos que levam à promoção da transição para a EC mediada por EIs. Neste trabalho, analisámos dados recolhidos através de uma revisão de literatura sistemática de modo a concretizar e caracterizar uma taxonomia para instrumentos de política focada em diferentes objetivos e baseada em evidências da literatura. Seis categorias de instrumentos centrais são exploradas: 1) Aumento de I&D, 2) Capacidades não-financeiras, 3) Capacidades de rede, 4) Aumento da procura, 5) Regulação e padrões, e 6) Análise tendências futuras. Os resultados obtidos reforçam a complexidade subjacente ao desenho de políticas de inovação. Conclui-se que uma abordagem por um lado direcionada para as diversas etapas dos ciclos de materiais, por outro intencional nas características dos instrumentos de política e das suas complementaridades, parece beneficiar a criação de inovações 'circulares' e a transição para a EC.

Palavras chave: Economia Circular; Eco-Inovação; Políticas de Inovação; Taxonomia

Classificações JEL: O e Q

Acknowledgements

I want to take the opportunity to extend my gratitude towards the people that have helped me along this last year.

First and foremost, I want to thank Professor Sandro Mendonça for the initial discussions, motivation and the support throughout the elaboration of this research.

Secondly, I want to express my most sincere gratitude towards Ana de Jesus for her relentless assistance and attentive monitoring that were crucial to this project.

My special thanks to Ana Correia Moutinho, who unknowingly has kickstarted this venture for me, and to André Nóvoa for listening and informally debating these and other relevant subjects.

Finally, I want to thank all my friends and family for the support, specially to Filipa who has cheered and encouraged me the most during this last year.

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1 Introduction

Ever since the first industrial revolution, the anthropogenic impact on the environment is threatening the stability of ecosystems at large leading, for instance, to worrying shifts in natural cycles, changes in atmospheric composition and loss of biodiversity (Goudie, 2018). In recent years, the circular economy (CE) concept has been defended, by academics and policymakers alike, as an alternative to the long-established paradigm of 'take-make-dispose' that have characterised human activities at a broad level (EMF, 2015). To mimic natural cycles, the CE proposes the emulation of self-renewing natural systems fostering the continuous use of resources in a 'closed loop' fashion.

Putting this concept in practice requires an 'holistic' approach that hinges on innovations (de Jesus *et al.*, 2018). Accordingly, examples in both theoretical literature and policy practices have stressed the relationship between CE and eco-innovations (EI), i.e., innovations that, intentionally or otherwise, originate net environmental improvements comparing to a 'business as usual' alternative (EIO, 2011). In this perspective, the CE is enabled by and depends on various technological and non-technological EI. On one hand, closing loops implies technological advances that promote changes and adaptations of infrastructures, machinery or products. On the other hand, the CE also depends on non-technological transformations such as shifts in consumer behaviour, innovative business models as well as support from government institutions and alignment of public policies (EIO, 2016; Ghisellini *et al.*, 2016).

Policymakers and scholars attempting to understand and act upon the complex interrelations and feedback mechanisms of an EI mediated transition to a CE can benefit from the contribution of numerous academic subjects that acknowledge this dynamic such as evolutionary economics (Nelson and Winter, 2002), national systems of innovation (Fagerberg and Sapprasert, 2011), social and technological transitions from a multi-level perspective (Geels, 2011) or strategic niche management (Nill and Kemp, 2009). Together, these themes emphasise the systemic character of innovation and the need for sound innovation policy measures capable of promoting not only the creation of knowledge but also its selection, adaptation and diffusion to enact the desired changes. In other words, a systemic understanding of how innovation policy can encourage EIs is crucial for the implementation of the CE.

The innovation policy literature often categorises policy instruments according to their mechanism or approach to promote changes, resulting in variations or developments of a widely accepted three-fold classification (regulation, market instruments and voluntary instruments). Still, since the attainment of grand socio-economic objectives such as a transition to a CE, is expected to occur as consequence of an adequate policy mix (del Río *et al.*, 2010; Kemp and Pontoglio, 2011) targeted at identified innovation problems within the system (Edquist, 2011), it can be argued that a goal-oriented classification for innovation policy provides is more adequate to support policymakers and practitioners that seek to promote the CE.

The innovation policy – circular economy – eco-innovation nexus is only now beginning to emerge as a research topic (Ghisellini *et al.*, 2016; Smol *et al.*, 2017; de Jesus and Mendonça, 2018; Milios, 2018). The discussion includes systemic views on the institutional and governmental drivers and barriers for this transition, however, as of yet, there is no consensus on how policy mixes can successfully promote EI activities to navigate socio-economic systems towards implementing the CE. A better understanding of the policy instruments underlying this transition is thus needed. The main objective of the present work is to propose and characterise a goal-oriented taxonomy for policy instruments that facilitate the EI mediated transition to the CE. Specifically, two research questions are addressed: What are the main categories of innovation policy instruments and how do they influence actors to engage in CE related innovation activities? How can policy mixes and the interplay of these instruments contribute to a systemic EI-mediated transition to the CE? To answer these questions, we performed a systemic review of publications that cover the research topics of circular economy, eco-innovation and innovation policies.

This work is divided as follows: Section 2 presents a revision on the underlying concepts for this work; the methodologies employed are described in Section 3; Section 4 begins the presentation of the results with a quantitative analysis on the obtained literary corpus, moves on to highlight some of the predominant considerations on innovation policy featured in the material under analysis, and closes with the presentation and characterization of the proposed taxonomy; Section 5 presents a discussion and interpretation of the results to explore integrated perspectives in innovation policies; and finally, a conclusion to highlight the main contributions, policy implications, limitations and avenues for future research is made in Section 6.

2 Concept review

A brief understanding of the concepts underlying this research is presented in this section. First, the CE and concept and contributions are presented. Then, we explore the definitions and mechanisms associated with EI. A concise presentation on innovation policy rationales and relevance for socio-economic systems is presented next. Finally, to frame our research, we briefly consider some mechanisms and typologies of policy instrument to assist the CE transition, present our objectives and research questions and outline the present work.

2.1 Zeroing in on a circular economy

The influence human activities have been having on the environment, particularly since the industrial revolution, has raised concerns among government bodies and world leaders. Since the mid-1900s, this situation has prompted sustainability movements and an increase of environmental awareness that gave way to the widespread of recycling practices, the development of resource and energy efficient technology and the establishment of targets for sustainability such as the Sustainable Development Goals (UN, 2016). Within that debate, the CE concept emerged as a promising approach to further reduce environmental and resource availability pressures envisioning an economy that is "*restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times*" (EMF, 2015: 2). It focuses on closing material loops and promoting zero waste practices in contrast to the 'take-make-dispose' paradigm. Rather than proposing a compromise between reduced resource consumption and economic performance, the CE is considered to be aligned with opportunities for job creation, innovative business development and 'decoupled' economic growth (EMF, 2015). This transition entails a reconfiguration of socio-economic systems at several levels, including industrial practices, supply chains, business models and consumer habits (Ghisellini *et al.*, 2016).

Worldwide, governmental institutions are progressively recognizing and incorporating CE practices in policymaking. The 1996 German 'Closed Substance Cycle and Waste Management Act' is one of the earliest laws to show an interest in material circulation (Dajian, 2008). In China, authorities have been putting in practice explicit CE policies at least since the 11th five year program in 2005 (Wu *et al.*, 2014). In 2014, the European Commission issued its communication 'Towards a circular economy: a zero waste programme for Europe' (EC, 2014), which followed by the 2015 package 'Closing the loop – An EU action plan for the Circular Economy' (EC, 2015) and more recently the 'European Strategy for Plastics in a Circular Economy' (EC, 2018). Nowadays policy measures towards CE have become global with examples from South America to South East Asia. India, for example, is now taking the first steps in implementing the CE in their governmental actions (Yaduvanshi *et al.*, 2016).

Conceptually, the CE is rooted in different schools of thought (Ghisellini *et al.*, 2016; Geissdoerfer *et al.*, 2017) that explored the linearity of economic systems (Pearce and Turner, 1990), industrial economics (Hay and Morris, 1991), general systems theory (Von Bertalanffy, 1972), industrial ecology (Frosch and Gallopoulos, 1989) and service-based business models over ownership of goods (Stahel, 1982). Over time, the CE and its application in real-world socio-economic systems and industrial practices developed along a panoply of other concepts such as industrial symbiosis (Chertow, 2000), eco-industrial parks (Lowe, 1997), cradle-to-cradle (Braungart *et al.*, 2007), reverse logistics (Dekker *et al.*, 2004), product-service systems (Tukker, 2015), green supply chain management (Sarkis *et al.*, 2011) and cleaner production (Fresner, 1998).

The various scholarly contributions on CE as a research topic have generated some conceptual leeway (Kirchherr *et al.*, 2017) and opportunities for new conceptual redefinitions (Geisendorf and Pietrulla, 2018). However, from an operational perspective, the CE is generally accepted to arise from a combination of technological innovations, such as waste-to-resources innovations and material and energy efficient methodologies, and innovations in business models and markets with a focus on the shared consumption, reuse, repair, refurbishment and recycling of products (de Jesus *et al.*, 2018). The CE can be decomposed to three fundamental strategies (Bocken *et al.*, 2016) (Figure 1): i) slowing resource loops by extending the life cycle of products (design for repair and remanufacturing, reuse, extended warranties product-service systems and sharing business models); ii) closing resource loops by turning wastes and by-products into secondary materials (recycling, reverse logistics, cradle-to-cradle, industrial symbiosis); iii) narrowing resources in loops by efficient use of materials and energy sources (resource and energy efficiency, renewable energy, environment-friendly materials).

In summary, the implementation of the CE comprehends a reconfiguration of socio-economic systems towards 'closed-loop' material cycles that doesn't compromise the economic performance of societies. A transition to such paradigm depends on the innovation activities that enable the necessary technical and organizational shifts.

2.2 Eco-innovations to improve environmental performance

Socio-economic transitions are processes intimately associated with gradual innovation-induced deviations from previous paradigms (Geels, 2010). Joseph Schumpeter, known for his work on the role of entrepreneurship and innovation in economic changes, first distinguished

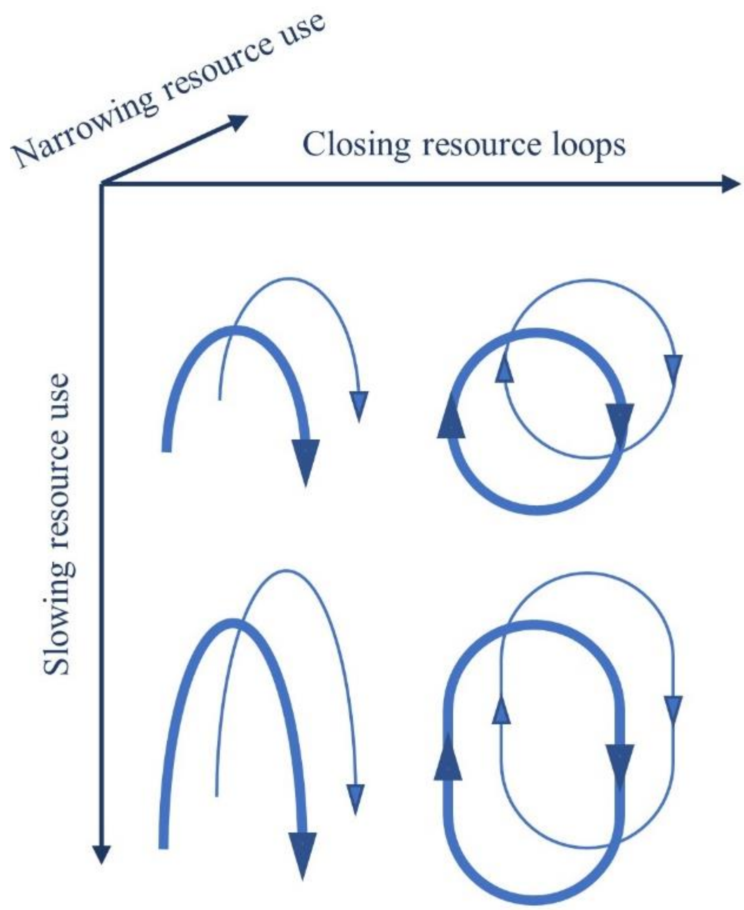

Figure 1: The circular economy entails three main strategies: slowing, narrowing and closing resource loops. (From: Bocken et al., 2016)

the knowledge creation event, or 'invention', from the knowledge use processes, or 'innovation' (Schumpeter, 1934). This separation realises that the impact of innovations depends not only on the occurrence of novelties but also on its subsequent improvements, user adaptation and adoption. Hence, the impact of a new product can be hindered if it fails to penetrate the market or adapt to the target needs. Moreover, the definition of novelty depends greatly on the context in consideration: an innovation can correspond to a novelty to the world but it can also relate to the introduction of an existing innovation in a new setting for the first time (Damanpour and Wischnevsky, 2006). As such, the innovation process, in a broad sense, encompasses different phases that include the creation, exploitation, adaptation and diffusion of innovations, and involve multiple agents in the system (Edler and Fagerberg, 2017)

Innovation processes have assumed a central role in sustainability concerns. Fussler and James (1996) first employed the term 'eco-innovation' to innovations that have a positive impact on the environment and, as it became a widely academically discussed topic, it spawned a myriad of definitions and applications for the term (Carrillo-Hermosilla *et al.*, 2009; Díaz-García *et al.*, 2015). While the enthusiasm and attention towards this subject stress its relevance in academic and political circles, its dispersion challenges the use of EI as a working concept. A comprehensive look on these conceptualizations points to some key characteristics of EIs: they provide overall environmental benefits from a life-cycle perspective and have an impact on socio-economic systems and the agents entailed (Kemp and Pearson, 2007; Pansera, 2011; de Jesus *et al.*, 2018).

Apart from drawing academic interest, the potential environmental gains and the prospect of economic benefits of EIs has attracted the attention of public institutions, governmental bodies and firms as well. For instance, the EU has financed a project called Measuring Eco-Innovation which had the objectives of offering conceptual clarification, identify challenges and explore indicators and implementation strategies for eco-innovations (Kemp and Pearson, 2007). The EU has also set up the Eco-Innovation Observatory, an initiative that aims at providing reliable information on eco-innovations for policymaking, firms and innovation centres (EIO, 2011, 2013, 2016). The OECD issued a number of reports focusing on eco-innovations as well, most notoriously, the Oslo manual guidelines for collecting and interpreting innovation data (OECD and Eurostat, 2005). There are other examples of initiatives that bridge the development of innovations across continents such as the ASEIC, an European-Asian Eco-Innovation platform for small and medium enterprises (SMEs) (ASEIC, 2011).

According to Rennings (2000), EIs can be distinguished between technological ('hardware' innovations) and non-technological ('software' innovations). Technological innovations can be further classified as curative and preventive. The former relates to technologies that allow the remediation of the environment such as the removal of pollutants from contaminated land or carbon dioxide from the atmosphere. In turn, preventive technologies aim at avoiding potential environmental damages before they take place. Furthermore, preventive technologies are considered additive if they focus on end-of-pipe solutions, i.e., pollution elimination from production outward flows (e.g. gas emissions, liquid streams or solid waste), and can include disposal methods, filters and recycling of wastes. Alternatively, innovations that target the cause of pollution directly in the material uptake, the transformation process or at the final product level are classified as integrated measures or cleaner production technologies and methodologies, e.g., the substitution of harmful additives for non-toxic alternatives, the removal of poisonous metals from the products, the decrease of the resources/product ratio or energy efficiency improvements. Non-technological EIs comprise mainly organizational, social or institutional changes that have positive impacts on the environment. Organizational EIs can include assessment mechanisms like audits in firms or new ways to conduct businesses such as green supply chain management (Sarkis *et al.*, 2011) or a shift from product-based to service-based business models and collaborative consumption models (Annarelli *et al.*, 2016). Social EIs relate to changes in people's behaviour and life styles towards pro-environment consumer patterns such as increased recycling habits or avoiding disposable items. Finally, institutional EIs refer to changes in the regulatory and policy frameworks towards institutional responses to sustainability problems.

EIs can be further distinguished between incremental and radical innovations (Hellström, 2007). The former relates to continuous improvements on existing technologies while the latter relates to innovations that are more disruptive towards existing technologic paradigms.

Drawing on the concept revision above, we consider EI in a broader sense to be any innovation process (creation, adoption, adaptation, diffusion, etc), radical or incremental, technological or non-technological, that holds the potential to create a net positive impact on the environment with expected long-term benefits to the socio-economic system.

This broad definition of EI implies that not all EIs advance CE goals such as closing material loops or avoid resource extraction. EIs enable any environmental improvement even if its impact does not necessarily represent a shift from linear economies. However, while EI and CE are distinct concepts, EIs play a central role in enabling CE practices at multiple levels (de Jesus *et al.*, 2018). Thus, adequate governance of EIs through innovation policy can contribute to the transition to the CE.

2.3 Innovation policy overview

The all-encompassing characteristics of policies in general implies an intrinsic influence on innovation processes. However, only in the aftermath of the Second World War did governments started to implement policies that explicitly attempted to solve innovation problems and promote the needed economic recovery (Edler and Fagerberg, 2017; Schot and Steinmueller, 2018). This led to the emergence of innovation policy as an academic topic in the late 1960s, with important contributions made by Professor Roy Rothwell from Science Policy Research Unit at the University of Sussex (Fagerberg, 2017). Nowadays, scholarly views on innovation policy have gathered influences from different lines of research contributing to further the understanding of its conception, rationales and implementation. However, a broad but practical innovation policy definition can be synthesised to be "*all combined actions that* *are undertaken by public organizations that influence innovation processes*" (Borrás and Edquist, 2013: 1513).

The earlier perspectives on innovation policy were characterised by a market-failure approach (Edler and Fagerberg, 2017). From a neoclassical standpoint, the establishment of innovation as a major driver of economic and social changes implies that a free-market would self-regulate innovation activities and private firms would spontaneously produce its optimal level for the best outcome for society, foregoing the need for large public investments or governmental interference in this area. However, firms can be discouraged from undertaking innovation investments due to the public-good characteristics of knowledge, i.e., often, the inventor is not able to retain all the potential economic gains that result from the knowledge creation event so long as it can be accessed and exploited by anyone at a trivial cost (Martin and Scott, 2000). This positive externality problem that firms face prompted traditional innovation policies such as public investment in R&D, subsidies for private R&D and strengthening intellectual propriety rights (Edler and Fagerberg, 2017). However, this focus on the supply side and on knowledge creation neglects the demand, adoption and diffusion phases of innovations and fails to recognise that "*technical change does not occur in a perfectly linear sequence, but through feedback loops within this system*" (OECD, 1997: 12).

Influenced by evolutionary economics (Dosi and Nelson, 1994), scholars recognised that the historical, political and social characteristics of a designated region established specific frameworks and networks between agents in the system (Freeman, 1995). As such, innovation policy efforts would benefit from understanding and adapting to the characteristics of the system in question. The national systems of innovation (NSI) approach was developed in the 1980s as a response to these challenges, with important contributions by Freeman, Lundvall and Nelson (Castellaci *et al.*, 2005). A traditional view on NSI focuses strongly on the 'components' in the system, that is, the institutions (government, policymakers, public authorities and institutions, etc.) that set the rules and boundaries, and the players, (industry operators, consumers, firms, research institutes, etc.) that act upon them (Edquist, 2011). However, in recent times, authors have placed a stronger emphasis on the innovation 'activities' or 'functions'[1] that take place in the system as a result of the dynamic interaction between

[1] (Edquist, 2011) refrains from using the term 'functions' to avoid confusion with the connotation given to 'functional analysis' practices in sociology, however, (Hekkert *et al.*, 2007) applies the term with a similar meaning and therefore, for practicality, 'activities' and 'functions' of innovations will be used interchangeably in the present work.

institutions and players that determine innovation processes (creation, diffusion, adoption, etc.) such as R&D or the formation of markets for new products (Hekkert *et al.*, 2007; Edquist, 2011). The importance of considering both the 'components' and the 'activities' within systems of innovations is well captured by Fagerberg (2017: 507):

> *"Arguably, an unsatisfactory state or 'problem' cannot be revealed by studying a single component of a system. What is required is an analysis of the technological dynamics of the national innovation system as whole. Only on this basis can it be possible to identify the processes (and policies) that prevent the system from developing satisfactorily"*

The NSI approach contrasts with a free-market perspective by placing government authorities at a central role in coordinating innovation at a nation level. Public intervention supports and facilitates the interactions between players, but also functions as a provider of relevant resources for firms such as training or financial resources as well as stimulates the demand for innovation in industrial sectors and consumers. This perspective of innovation systems has been recognised far and wide by government authorities and public organizations contributing to their critical appreciation of innovation processes. For instance, the Organization of Economic Co-operation and Development has issued several reports adopting system-level evaluations of national innovation policies (OECD, 1997).

The functions of innovation processes of information retention, variety creation and alternative selection are well emphasised by evolutionary economics (Hekkert *et al.*, 2007). The dynamics between these functions and the actors involved is crucial for the emergence of innovations in innovation systems. For instance, while individual creation events increase variety and prevent stagnation in the long-run, the selection, adaptation and diffusion of innovations is most likely dependent on networks, market dynamics and organizations that invariably avoid low potential solutions in favour of promising ones. An unbalance between these functions can lead to path-dependence or 'lock-in' situations in which a 'technology regime' becomes entrenched even if it is no longer favourable (Geels, 2011). Environmental concerns in particular have challenged some technologies that were well established in the system such as the use of fossil fuels to produce energy (Nill and Kemp, 2009). Thus, a desired socio-economic transition might be hampered due to already established infrastructures, supply chains and commercial networks from prevailing technological regimes, further validating public policy intervention (Edler and Fagerberg, 2017).

Socio-technical transitions to sustainability has become an academic topic of interest. Geels (2011) proposes a multi-level perspective that regards transitions as a non-linear process resulting from the interplay of developments in three separate analytical levels: the niches (where radical innovations take place), regimes (where established practices and technologies are implemented and stabilised) and landscapes (institutional and physical environment). Transitions, that is, shifts in regimes, are influenced by the substantially different practices and technologies developed at the niche level and the exogenous factors from the landscape (e.g. policies) that influence the interaction between niches and regime. Within this framework, the concept of strategic niche management innovation emerged as a policy strategy to create 'protected spaces' for innovations at the niche level (Nill and Kemp, 2009). Sheltered from market pressures, experimentation and improvements on innovations can inform developers about their desirability and applicability. This strategy is particularly important to allow radical innovations to attain a market-ready level, at which point a controlled phase-out of the protected space would take place.

Leveraging on the above contributions, innovation policy can be regarded as the combination of public actions that influence players in engaging with innovation activities in the system[2], ultimately contributing to socio-technological transitions. Policymakers can thus attempt to design 'circular' innovation instruments that encourage an EI-mediated transition to the CE.

2.4 Operationalise a taxonomy of 'circular' innovation instruments

Policy instruments can be defined as the "*concrete and specified operational forms of intervention by public authorities*" (Bemelmans-Videc *et al.*, 2011: 4). Because instruments may be designed to target different problems, their combination in 'policy mixes' can trigger different outcomes. Moreover, it is the effect of these outcomes that will contribute to the attainment of the socio-economic grand objectives determined through political processes (growth, employment, sustainability, etc.) (Borrás and Edquist, 2013). This stresses the importance of knowing what type of instruments policymakers have at their disposal, what impact does their interplay have on innovation processes and how does that translate towards the objectives that are pursued.

[2] Because of its broad scope, this definition may include policies that do not pursue any innovation goal but that ultimately drive innovation activities. For instance, (Kemp and Pontoglio, 2011) offer a perspective on the impacts of environmental policies on innovation.

The literature often refers to three broad types of policy instruments: i) market-based instruments, ii) regulatory instruments, and iii) information and awareness instruments. This perspective is commonly found to be figuratively expressed as the 'carrots', 'sticks' and 'sermons' of public policy (Bemelmans-Videc *et al.*, 2011). Market-based instruments are mechanisms that attempt to drive innovations through the application of economic based pressures and include both taxes and subsidies. Regulatory instruments are mandatory parameters imposed on actors through a 'command-and-control' approach, including bans, targets and standards. Information and awareness instruments report to a set of policies that generically contribute to increase education and awareness of actors in the system and can be conveyed in educational programmes or voluntary agreements. Although this three-fold approach remains appealing, its over simplistic terms do not fully encompass and describe the variety and range of innovation activities undertaken in an innovation system which has prompted other perspectives. Edler and Georghiou (2007) propose a taxonomy for innovation policy that emphasises the separation between supply-push and demand-pull innovation instruments. Borrás and Edquist (2013) offer a classification of innovation instruments following identified innovation activities in the system. More recently, Edler *et al.* (2016) employed a goal-oriented framework to propose a typology of innovation policy instruments grounded on case-study evidence. This instrument categories featured in this comprehensive typology include regulation policies, subsidies and education programmes but also policies focused on the interaction between organizations, market drivers, knowledge transfer and foresight, *inter alia*.

As a desirable socio-economic objective, the transition to a CE relies strongly on the possibilities brought forward by eco-innovations (de Jesus and Mendonça, 2018; de Jesus *et al.*, 2018). The circulation of materials with subsequent (and ideally infinite) value creation processes implies the need for innovative technology to transform substances from wastes to resources (e.g. recycling) but also significant reconfigurations of industrial networks (e.g. industrial symbiosis), markets (e.g. PSS, second hand) and innovative supply chains (e.g. reverse logistics). Thus, policy mixes designed to solve the underlying innovation problems may encourage the implementation of CE practices. We attempt to contribute to this debate by proposing and characterizing a goal-oriented taxonomy for innovation policy instruments that promote the CE transition.

3 Methodology

Considering the bibliographic-oriented methodologies employed in existing classifications of policy instruments (Borrás and Edquist, 2013; Edler *et al.*, 2016), it seems appropriate to use a systematic review to gather information and build the proposed taxonomy. A systematic review differs from a traditional narrative review in the application of a search protocol that includes explicit criteria to find relevant literature. It is therefore a more objective, replicable and scientific review procedure that enables the comparability and transparency of unbiased results (Becheikh *et al.*, 2006; Patala *et al.*, 2014). Moreover, because this methodology allows the user to design the search criteria according to their specific research questions, it offers a way to build a literary corpus that articulates the confluence of different research topics. Figure 2 presents a graphic summary of the methodology steps taken.

3.1 Building the literary corpus

There are two important elements to perform the systematic review: the definition of the qualifying criteria and the selection of the databases under scrutiny.

In light of our objectives, the search query had to reflect the overlapping of themes involved, that is, the ‘circular economy’, ‘eco-innovation’ and ‘innovation policy’. de Jesus and Mendonça (2018) and de Jesus *et al.* (2017) have performed systematic reviews of literature sitting in the confluence of CE and EI research topics through the application of the following keyword Boolean search query: "innovat*" AND ("circul* econom*" OR "industrial symbiosis" OR "industrial ecology" OR "urban symbiosis" OR "eco-industrial park")[3]. Inspired by this, we designed our query following their approach but added one more selector referring to the policy approach of our work to fine-tune the search towards our objectives. The resulting query used to select the literary corpus was: "innovat*" AND ("circul* econom*" OR "industrial symbiosis" OR "industrial ecology" OR "urban symbiosis" OR "eco-industrial park") AND "polic*".

[3] de Jesus and Mendonça (2018) and de Jesus *et al.* (2017) used four keywords found consistently in initial searches using the preliminary query “innovation” AND “circular economy” to expand their search, resulting in their inclusion as an alternative to the CE descriptor.

We performed Boolean searches on the titles, abstracts and keywords of publications integrating the Web of Science (WoS) and Scopus databases. These concentrate the largest number of peer-reviewed journals and have long-term worldwide coverage (de Jesus and Mendonça, 2018). The search was further limited to articles or reviews written in English and published until 2017. The combined searches on both databases yielded 139 unique documents[4]. An initial screening through the abstracts identified 28 documents that were not relevant for the subjects at hand and were thus removed from the analysis. The resulting 111 were considered to be policy-oriented publications that included considerations on the role of EIs in the CE transition (see Annex A for a full list). This final corpus was read in full to extract evidence-based data for the analysis.

3.2 Criteria for qualitative analysis

Drawing on the objectives of the present work, we opted to use an existing classification for innovation policy instruments as a 'scaffold' to organise the data collected. To this end, we selected the typology suggested by Edler *et al.* (2016) based on three important arguments: firstly, it is based on bibliographic evidences, drawing a parallel to the methodology employed in the present work; secondly, it is goal-oriented which reflect the underlying understanding that the CE transition may be driven by focussed innovation activities; and finally, it covers a wide scope of policy instruments. However, because our literary corpus resulted from a targeted search methodology, following such a comprehensive and thorough typology designed for innovation policies in general seemed unfeasible. Therefore, based on the grouping of instruments described by the same authors in Edler and Fagerberg (2017: 11), we adapted their typology to build an initial broad classification for the policy instruments found in the literature. A total of six innovation policy core goals are thus distinguished: 1) increase R&D spending, 2) support non-financial capabilities, 3) strengthen network capabilities, 4) stimulate demand, 5) regulation and standardization, and 6) foresight. In bibliometric studies, new categories may be inserted according with new topics that arise (Lazzarotti *et al.*, 2011). As such, upon reviewing the evidence, new sub-categories were formed to accommodate further discrete policy goals, adding more resolution to the proposed taxonomy[5].

[4] As of 12/03/2018

[5] See Figure 4 for a complete view of the taxonomy.

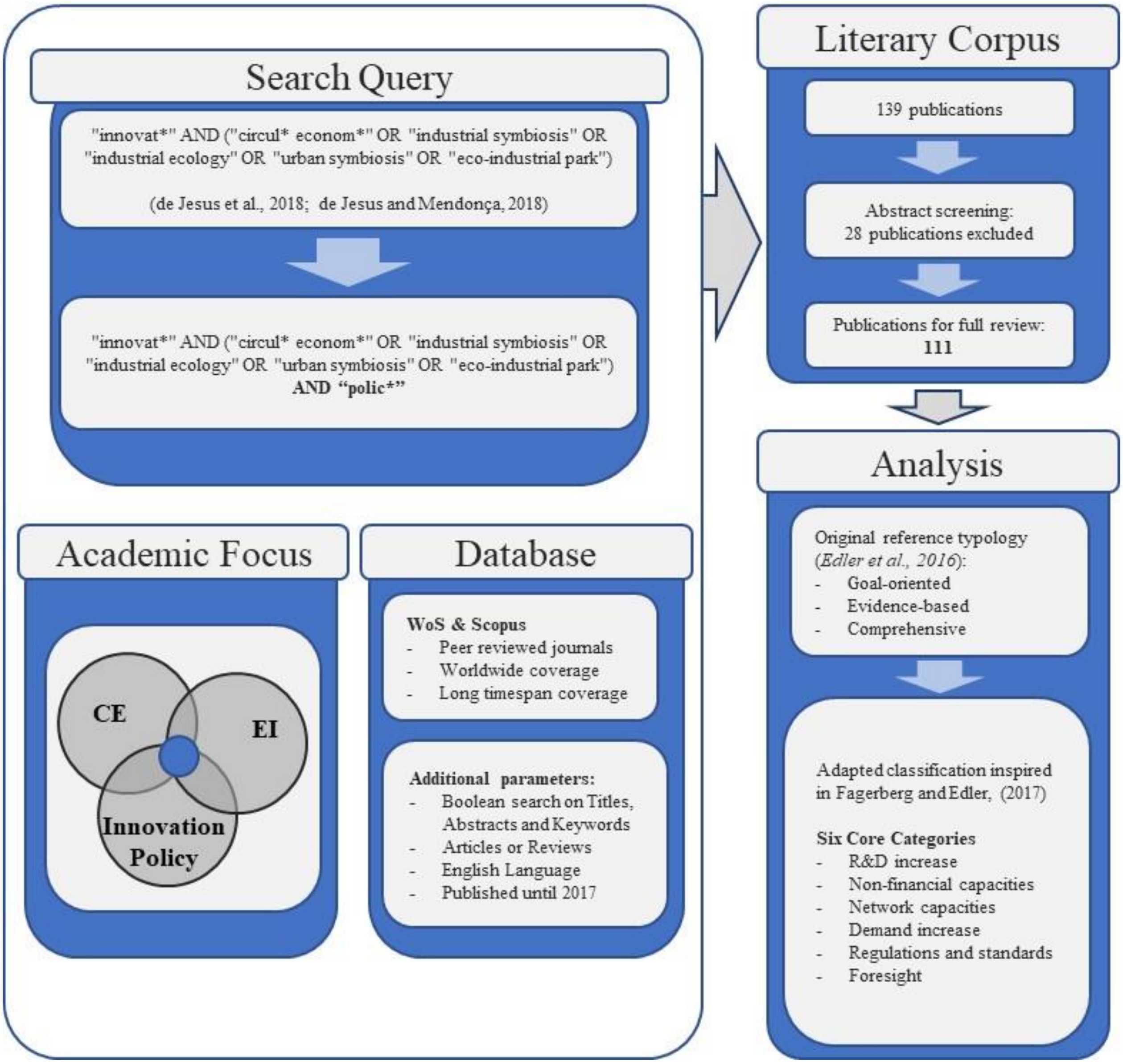

Figure 2: Workflow of the systematic review - After defining the academic focus, the search query was designed and applied to the chosen databases. An initial abstract screening on the resulting 139 publications excluded 28, forming a literary corpus totalling 111 publications. These were read in full to collect data that was organised according to six core categories for innovation policy instruments.

The categorization of the policy instruments was not straightforward and involved an inherent degree of operator subjectivity. Innovation policy mixes affect actors and innovation activities in multiple ways. As a result, a taxonomic distinction of policy instruments based on their impact is artificial (Edquist, 2011; Kemp and Pontoglio, 2011; Borrás and Edquist, 2013). Indeed, the literature analysis pointed to policy instruments that contributed to more than one policy goal. For instance, workshops in support for CE may simultaneously contribute to facilitate access to expertise while strengthening of the network and creating of a common view that signals future trends. However, the purpose of this taxonomy is not to provide an exhaustive classification of impermeable and rigid categories but to contribute to the understanding of how the different instruments address the innovation goals that drive the CE transition. Therefore, this subjectivity was not perceived as an impediment to our objectives.

4 Results of the literature review

The results obtained with the analysis are exposed in this section. This section is divided in three main themes. First, we present a qualitative description of the articles that comprise the literary corpus under scrutiny. Next, supported by the evidence, we explore a set of main considerations that emerged from an initial overview of the material to provide a better framing for the analysis. In the final sub-section, we present and characterise the goal-oriented taxonomy for innovation policies relevant for the CE transition.

4.1 Descriptive structure of the corpus

The resulting corpus was comprised of a total 111 publications. A total of 55 articles could be found on both databases whereas 22 articles and 34 articles were found exclusively on Scopus and WoS, respectively. The chronological distribution of the articles in the analysed set is severely asymmetrical (Figure 3) with more than half being published between 2015 and 2017 while only 3 articles were published between 1997 and 1999. A total of 70 different sources was identified. Table 1 shows the number of articles published on the 5 journals with at least 3 publications (51.4% of sample). Most articles were published in Journal of Cleaner Production (26) followed by Journal of Industrial Ecology (19), comprising over one third of the sample (40,5%). This is revealing as both journals are highly focused on sustainable and environmental concerns with an emphasis on CE related topics.

Table 1: Sources that contributed to the literary corpus with more than 3 publications

Sources	Count	%	Cumulative %
Journal of Cleaner Production	26	23,4	23,4
Journal of Industrial Ecology	19	17,1	40,5
Sustainability	6	5,4	45,9
Environmental Science and Pollution Research	3	2,7	48,6
Minerals Engineering	3	2,7	51,4

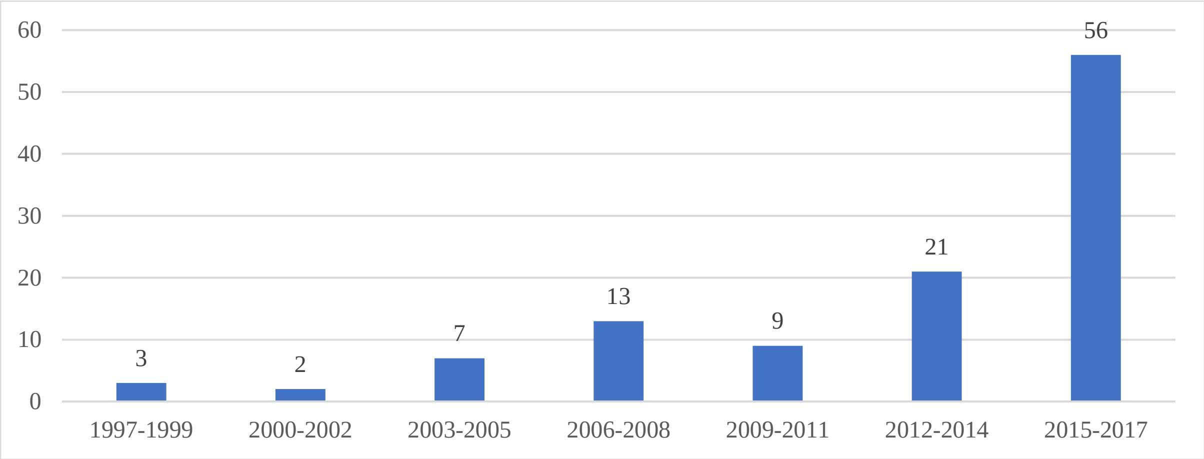

Figure 3: Number of publications in the literary corpus per 3-year period (own elaboration).

4.2 Overall considerations on the literature analysed

Based on the literature analysis, this sub-section presents various considerations that surfaced from a first qualitative exploration of our findings. The subjects presented here point to overarching features of policy mixes that may improve their impact towards an EI mediated transition to a CE. Three considerations are thus presented: firstly, we look at strategies for collaboration and mitigation of the information asymmetry present between regulators and compliant agents in the system; secondly, we address the concern for radical and incremental innovations outcomes in the system; and finally, we present data regarding the implementation of market-based instruments and strict regulations and their role in promoting innovation activities.

While the themes surveyed in this sub-section may already point to some distinction between policy approaches, its purpose is not to define instrument categories but to present themes that the literature suggests considering when designing policy mixes with an orientation towards CE implementation. As such, the main purpose of this initial approach to our data is to provide a better frame and understanding for the taxonomy proposed in detail in the next sub-section (see 4.3).

4.2.1 Information asymmetries and collaboration

The cooperation between public authorities and private entities in the co-design of effective policies as a measure to decrease the inherent information asymmetries is brought forward by the data. Yarime (2007) points to the importance of maintaining information loops with governments to design flexible regulations so that their implementation is in line with the available technology. The author suggests that when there is new technology emerging "*an expert committee could conduct technical evaluation through close communication and* *information exchange with industry*" (Yarime 2007: 134). He further concludes that "*with the existence of flexibility in regulatory implementation, the findings of the expert committee could contribute to revising the original schedule*" (Yarime 2007: 134). The importance of flexibility and firm discretion in policy making to stimulate EIs is addressed by other authors (Bergquist *et al.*, 2013; Hu and Zhang, 2015). Bergquist *et al.* (2013) analyse the interaction and cooperation in policy design between regulators and industries in Sweden during the period 1970-1990 and conclude that "*the Swedish policy style seeking long-term cooperation and consensus between regulators and the industry (also in terms of R&D) encouraged the implementation of process-internal pollution abatement technology*" (Bergquist *et al.* 2013: 17). This could result in regulation that is better adjusted to the firm's reality and possibly implemented over a comfortable period of time to maximise innovative reactions by the complier firms (for more on compliance periods, see 4.2.3). In Finland, the by-product criteria scheme reduces information asymmetries by allowing industry operators to submit a waste material to evaluation so that authorities may determine the criteria used to classify such waste as by-product (Pajunen *et al.*, 2013; Levänen, 2015). Such mechanism facilitates the issuing of licences that allow the reintroduction of these materials back in production loops. Volunteer reporting of CO2 by polluting industries may be another form of proximity between regulator agents and firms. Regarding the iron industry in Nepal, Kharel and Charmondusit (2008: 1387) argue that this approach can encourage "*maintaining the tax exemption quantity of CO2 emission, if government brings the policy of carbon-tax in future*". Corder *et al.* (2015) suggest the application of co-regulation approaches such as the National Television and Computer Recycling Scheme in Australia where industries take responsibility for waste televisions and computers at an increasingly progressive rate from 30 per cent in 2012-13 to 80 per cent by 2021-22, whereas the government is responsible for the remainder.

As evidenced, policies can be designed to include mechanisms that reduce the information asymmetries between regulators and compliant agents in the system. In this respect, a core idea that emerges from the literature analysis is that authorities should accompany regulatory measures with an assessment of the technological and financial capabilities of firms. This proximity may also result in collaborations in recycling efforts and the co-design of the criteria that defines by-products, allowing their reintegration in material loops. Thus, such considerations in policy design may benefit innovation activities in the system towards the CE.

4.2.2 Balancing radical and incremental innovations

The literary corpus under analysis illustrates the impact that different policy approaches may have in driving radical or incremental innovations in the system. This influence on innovative outcomes is well illustrated by Yarime (2007) in a comparison between the phase out of mercury pollutants associated with Chlor-Alkali industries in Japan and Europe. In Western Europe, authorities have implemented emission standards that, while not strong enough to drive radical, cleaner production technologies, incited companies to opt for end-of-pipe technologies to keep the amounts of pollutant in outward streams within compliant intervals. As a result of these incremental innovations, the use of mercury emitting technology was encouraged. Contrarily, in Japan, the incidence of the mercury-induced Minamata Disease on the population built strong public pressures on authorities resulting in swift and strict mercury bans for the industry and the adoption of other mercury-free methodologies. However, because the regulation was implemented in a short time period, firms had little capacity to conduct proper evaluations of alternative technologies available and incurred in large investments to adopt suboptimal technologies. This example points to the importance of conserving a certain level of diversification available in innovation systems to facilitate transitions in face of environmental, public or governmental pressures. The creation of ‘protected spaces’, as advanced by the strategic niche management (SNM) approach (Nill and Kemp, 2009), may help to develop and mature innovations that differ significantly from the current technologic regime, reducing the costs of adaptation for agents in the innovation system when facing such pressures.

Evidences from the literature analysed support the SNM as an important approach to facilitate CE practices. For instance, Barrie *et al.* (2017: 27) argue that the transition to a CE “*can be achieved through multiple protected spaces targeted, for example, at key circular economy growth markets such as renewable energy, biorefinery, remanufacturing, sustainable mobility and the sharing economy, to co-evolve*”. However, in their view, public governance over a SNM strategy is inefficient as information asymmetries lead to a poor understanding of the dynamics and communication of objectives resulting in uncoordinated efforts. To facilitate communication and expectations for the ‘protected spaces’ towards the CE transition, the authors suggest the creation of a triple-helix system intermediary that is governed by research agents, industries and authorities industries: “*the transformation of a ‘protected space’ into a triple helix ‘consensus space’ upon the confluence of the ‘knowledge space’ (pitched by academia) and ‘innovation space’ (pitched by industry) provides the social, cultural, economic, technological and environmental conditions for sustainable innovation and the subsequent* *emergence of a circular economy*" (Barrie *et al.* 2017: 42). Adamides and Mouzakitis (2009) analyse the contributions of SNM to the CE from the perspective of industrial development. They conduct a case study approach to investigate the role of SNM in the transition and formation of industrial ecosystems and eco-industrial parks. While, according to the authors, none of the industrial regions analysed identifies itself as technological niches, they propose a set of conditions that can instigate industrial ecosystem projects to leverage on SNM and technological niches to shift the barriers imposed in current production technology regimes.

In brief, depending on its design and characteristics, innovation policy can drive innovation output towards radical or incremental innovations. As pointed out by the exposition above, lenient policies may encourage incremental innovation activities such as the development and adoption of end-of-pipe pollution abatement technologies. Because incremental innovations develop from existing innovations, this may contribute to further technologic entrenchment and establishment of a regime. On the other hand, stringent regulations can impose shifts in methodologies which can be an opportunity for radical solutions in markets. However, if the implementation of such regulation takes place in a short period of time and there are no good alternatives available, firms may end up with suboptimal technologies at elevated costs. Policy approaches such as the SNM can mitigate such costs by providing the system with a diversification of innovations that deviate substantially from the established methodologies. Such approaches have relevance for a transition to the CE as it can benefit greatly from radical innovations that deviate from the linear economic paradigm (Ghisellini *et al.*, 2016).

4.2.3 Market-based instruments and command-and-control

The efficiency of different innovation policy approaches is a widely debated theme in academia, particularly regarding market-based instruments such as taxes, trading schemes and subsidies, and stricter regulation, often referred to as a command-and-control approach (del Río *et al.*, 2010). While command-and-control remains an important strategy to drive compliant behaviour from polluting agents, market-based solutions have gathered great support among scholars as they are found to be highly efficient instruments to stimulate innovations since "*their advantage is that they give permanent incentives for further, cost-efficient emissions reductions*" (Rennings 2000: 325). René Kemp and Pontoglio (2011) advance that market-based instruments as drivers of mostly incremental innovations whereas radical innovations are promoted mainly by carefully designed command-and-control approaches.

The present analysis further contributed to this debate. While some authors suggest the use of both instruments (Thomas and Graedel, 2003), others may present more polarised stances. For instance, Pajunen *et al.* (2013) criticises market-based instruments by pointing to the lack of clear evidences that show the effect of taxes in environmental performance adding that "*a general conclusion based on existing analyses is that these taxes are usually so low that clear environmental impacts are difficult to find*" (Pajunen *et al.*, 2013: 148). Alternatively, in their study on the implementation of eco-efficiency technologies in water systems, Angelis-Dimakis *et al.* (2016) reported that in one of the case studies, the proposed scenario was not economically favourable but that implementation would eventually take place regardless due to recent stricter legislation on pollution removal exemplifying how *"stringent environmental regulations can be an effective driver for promoting eco-innovative technologies*" (Angelis-Dimakis *et al.*, 2016: 205). Moreover, command-and-control regulation may have a crucial role in addressing urgent environmental problems that wouldn't be resolved in due time through taxation or other market-based instruments, particularly in the case of bans on pollutants. This is emphasised in the case-study research regarding mercury pollution from Chlor-Alkali industries previously addressed (see Section 4.2.2) by Yarime (2007). However, subsequent legislations mandated the remaining plants to adopt the better performing ion-exchange membrane technology within a period of 5 years, leaving operators with more time to adjust and adapt to the new methodology and resources. These observations are in line with the analysis brought forward by Bergquist *et al.* (2013) that illustrate how "*the combination of ambitious performance standards and extended compliance periods may give substantial incentives for technological change while at the same time avoiding excessive compliance costs for competitive industrial sectors*" (Bergquist *et al.* 2013: 17). Deutz (2009) also reports on the benefits of implementing regulations over time, referring to the EU Producer Responsibility Directives that stipulate performance standards for producers, namely the Packaging Waste, End of Life Vehicles and Waste Electronic and Electric Equipment: "*Each Directive states that targets for the recycling and recovery of material would become increasingly stringent over time. This signals both recognition of current technical limitations, and an imperative for technological innovation*" (Deutz, 2009: 282).

As explored above, market-based instruments can be applied to induce a constant incentive on lower-cost incremental innovation activities in the system. However, a command-and-control approach can stimulate innovations effectively if it is flexible and comprehensive of the current technology status of operators in the targeted industry. This may result in regulation designed with extended compliance periods or progressive stringency over a period of time signalling a clear direction so that agents in the system can plan their options ahead. The literature points to the benefits of such policy design in the CE transition in, for instance, the implementation of targets for recycling, standards for product design that facilitate material cycles or in the phase-out of harmful substances or single-use products. The results thus suggest that the recognition for the current technological limitations coupled with an emphasis on future regulatory pressures are relevant considerations for the implementation of CE-enabling innovation policies.

4.3 Goal-oriented taxonomy for policy instruments

In this sub-section, a goal-oriented taxonomy for innovation policy instruments that may facilitate the CE transition is presented. The data collected from the literature analysis was used to characterise the various goal-oriented categories, according to the proposed methodology (see 3.2). Each of the following six sub-sections represent one core branch of the innovation instruments taxonomy. After presenting the sub-categories and the main evidences for each one, the main overall implications for the CE transition are presented. When needed, supplementary publications are used to properly frame the data.

4.3.1 R&D expenditure

As seen in Section 2.3, the public-good nature of innovations created a positive externality problem. Because EIs are innovations that have a positive environmental impact, positive externalities arise from both features (Rennings, 2000). Public support for research and development (R&D) efforts is an immediate measure to tackle the double externality problem associated with EI development and increase its supply in the innovation system (del Río *et al.*, 2010). As such, this measure can have relevant implications in increasing the supply of CE-enabling innovations in socio-economic systems. In general, public support for R&D can take place by implementing direct subsidies to firm R&D (Table 2).

Table 2: Summary of R&D increase policies (own elaboration)

Policy focus	Instrument	Examples in Literature
Increase innovation supply	Public financing of multidisciplinary CE projects	Eco-Town initiative

Evidences for direct public support found in the literature analysis are mostly circumscribed to heavily directional efforts such as sustainability pilot projects and CE-focused national programmes. For instance, in Canada, the Alberta authorities are investing in different pollution abatement projects, including "*a total of $1.3 billion to fund two large-scale carbon capture and storage (CCS) projects for the reduction of Alberta's GHG emissions*" (A.B. Avagyan 2017: 20242). In Japan, the well documented Eco-Town initiative included subsidies that covered part of the financial expenditures of various projects implemented as well as subsidies to support firm hardware innovations (Chen *et al.*, 2012). The subsidies were distributed in a decentralised, but structured manner, and showed concerns for a balance between soft and hardware innovations, which proved to be very successful. The subsidy for software projects "*was limited to a maximum of 50% of the project costs, typically in the range of 3 to 5 million Japanese yen*" while "*the total amount of the subsidy for the 60 hardware projects was about 60 billion JPY (US$782.5 million)*" (Chen *et al.* 2012: 131), with an average of 36% coverage of total investment. On a different account, also emerging from Japan, public authorities have supported Taiheiyo Cement corporation to develop an innovative cement made with municipal waste incineration ashes called 'Ecocement' (Carrillo-Hermosilla *et al.*, 2010). Interestingly, in an illustrative example of policy mixes that articulate supply and demand for eco-innovations, this product was included "*into the cement standard specification after consultation with stakeholders*" (Carrillo-Hermosilla *et al.*, 2010: 1079). Addressing the issue of poor private R&D investment, Albertario (2016) proposes a credit mechanism mediated by government authorities to capture confidence from investors. The author suggests that governments can use part of the savings that result from implementing EIs to pay the lenders that financed the corresponding R&D activities in the first place. In this way "*the positive cash flows state budget (…) paid in advance by lenders (…) should finance the private sector by providing innovative eco tools*" (Albertario, 2016: 6).

Surprisingly, while these R&D support measures are in the genesis of innovation policy, they are often pointed out as lacking in the innovation systems, particularly in case studies from China on eco-industrial development (Dong *et al.*, 2013, 2014; Hodgson *et al.*, 2016; Zhe *et al.*, 2016; Fang *et al.*, 2017; Li *et al.*, 2017). Accordingly, Matus *et al.* (2012) offer some criticism towards Chinese authorities underinvestment of basic research in green chemistry pointing out potential consequences of insufficient transformative green technologies production to tackle sustainable challenges in the long-run.

Criticism for direct funding of private R&D points to the risk of 'picking winners' which might lead to technological lock-ins "*if a diverse range of technology options are not supported*" (del Río *et al.*, 2010: 546).

In contrast with this direct support for firm R&D, governments may adopt an undirected approach usually by creating tax breaks in R&D expenditures, (Kemp, 2011). However, this mechanism was not explored in the publications analysed[6]. This approach is preferred by neoclassical economists as it does not favour any particular sector, allowing interfirm competitiveness and market pressures to be the main driver for innovation (Kemp, 2011). However, 'technology-blind' R&D policies may give rise to windfall profits and reduced additionality by funding research that would have taken place anyway (Kemp, 2011). Thus, while it appears to be a good measure to increase innovation activities across-the-board, it may be an inefficient policy instrument to create a focus on CE-related innovation processes.

4.3.1.1 Main overall implications

Drawing on the evidence, R&D support policies are important mechanisms that can drive private entities to undertake investments in EIs that lead to CE practices. While there is the risk of contributing to technology 'lock-in' by supporting particular technologies early on, the examples above reinforce the idea that public spending in private R&D can be advantageous to test CE practices in smaller scales and push CE enabling products in markets, particularly for the development of innovations that may have low marked demand (Table 2). On the other hand, an undirected strategy encompassing tax reductions on R&D expenditures and other financial mechanisms for private actors across the board may drive innovative activities in firms but may also be ineffective to channel that effort towards CE and EIs. Thus, to be effective in promoting the CE transition, R&D support instruments can be articulated with other demand-oriented instruments and should rely on expert judgement to assure that the proposed innovation projects would not have taken place otherwise and evaluate its impact towards the CE transition.

4.3.2 Non-financial support

Increasing the financial capacity of an innovation system can spur R&D activities contributing to the supply and diversity of innovations. However, public policies that target non-financial capacities are essential to guarantee the generation, use, continuous improvement and adaptation of such innovations. As explained in an OCDE report (2015: 6), "*non-financial*

[6] It is only mentioned in passing in del Río *et al.*, (2010)

support measures, e.g. training, mentoring and network development, including for SMEs, are an important component of the overall policy mix, as lack of funding is only one of the barriers that hold back innovation". In this section we will focus on two sets of instruments that aim to contribute to these innovation functions[7] (Table 3): training of skilled personnel and decision-makers, and facilitating access to expertise and innovations.

Table 3: Summary of non-financial policies (own elaboration).

Policy focus	Instrument	Examples in Literature
Training and skills	Training programmes to raise skills of agents in CE and application of EIs	Training in CP
Access to expertise	Governmental agencies to assist firms	MOTIVA, WRAP
	Knowledge sharing schemes	Workshops; On-site demonstrations
	Incentives to expert consultancy	Tax credit for consultancy expenditure

4.3.2.1 Training and skills instruments

Skills and innovations have been considered to be the twin engine of economic growth (Lloyd-Ellis and Roberts, 2002). As evidenced in the present analysis, public authorities may seek to implement policies dedicated at training and increasing the skills of players in the innovation system. For instance, (Rejeski, 1999) Rizos *et al.* (2016) identifies the lack of technical and technological know-how as one important barrier for the implementation of CE practices in European SME observing that, inevitably, "*a new technology needs to be operated with existing staff and knowledge and, if that is insufficient, then the technology will not be adopted*" (Rizos *et al.*, 2016: 12). In a study regarding green chemistry in China, Matus *et al.* (2012) also identify the lack of properly trained and skilled personnel in firms as a barrier to innovation. In their view, training initiatives should not only target engineers and operators but also decision makers in firms since "*they do need some basic level of understanding in these areas (…) if they are to manage their implementation*" (Matus *et al.*, 2012: 198). The literature underlined some examples of training policies in practice. The Government of Slovenia, for instance, provides training and skill training to young farmers to increase CE practices and innovations in agrarian systems (Slavič, 2017). In exploring the case study of Liaoning, China, Geng *et al.* (2010) report that one of the major efforts carried out by the Liaoning Cleaner Production Centre, a centre that encourages cleaner production practices in the province, are training courses to improve

[7] Although network policies target non-financial capabilities of innovation systems, they are explored as a dedicated policy instrument core category in Section 4.3.3.

knowledge on cleaner production in industries. International initiatives carried out in the same region also promote training workshops to improve environmental management in coastal areas. Acknowledging the difficulty to attract firms to join training programs, the authors suggest that "*the training program should be specifically designed to meet the local demands*" (Geng *et al.*, 2010: 1506).

4.3.2.2 Access to expertise instruments

Governments can also have a role in increasing non-financial capacity of the system by implementing programs and other policies that facilitate access to expertise for firms. These initiatives may provide consultancy and advisory services for firm innovation, facilitating knowledge transfer and innovation adoption (Bessant and Rush, 1995). Using a sample from U.S. firms, Simpson (2012) identifies the importance of such policies stressing that knowledge resources play an important role as a mediator between regulatory pressures and environmental performance. Focussing on waste management issues, the author concludes that firms "*may not be able to identify efficient responses to such pressures if they are unaware of all of their potential waste reduction options*" (Simpson, 2012: 38). Pajunen *et al.* (2013) refer to two different national initiatives that address the need for this non-financial support in firm's waste management. In Finland, an inter-ministerial effort set up a material efficiency centre together with MOTIVA, an agency that aids firms and other actors in improving energy and material efficiency by providing "*advice and services on energy and materials efficiency including audits and tools, energy efficiency agreements and sustainable technology procurement*" (Pajunen *et al.*, 2013: 148). In the UK, the Waste and Resources Action Programme (WRAP) develops campaigns and initiatives targeting different actors in the system to adopt CE practices in order to encourage better design and informed consumption and thus "*help reduce waste and make it easier to recycle, repair and to re-use as much waste as possible*" (Pajunen *et al.*, 2013: 148). Brears (2015) offers an account of these mechanisms taking place at an international level through EU funded programs that conduct business trips for EU SMEs in Asia to promote knowledge transfer and business opportunities between firms. In the Liaoning province in China, the Liaoning Clean Production Centre has established a scheme that allows polluting industries to raise their demands on specific clean technologies so that the centre can seek potential solutions through public bidding and dedicated research programs (Geng *et al.*, 2010). If there is no available solution within the province, "*this center will contact other organizations outside the province for help*" (Geng *et al.*, 2010: 1504). According to evidence from the literature, innovation policies may further include workshops focused on proving access to expert knowledge. For instance, Velenturf (2016: 128) suggests that UK governmental organisations such as the Environment Agency could engage waste producing companies in workshops "*to explore technical possibilities, emphasise potential economic benefits and discuss legislative possibilities*". In Singapore, governmental bodies host environmental workshops with the purpose of connecting experts and corporations, having implemented the Programme for Environmental Experiential Learning that showcases on-site practical uses of eco-innovations to interested organizations (Valentine, 2016). Also in Singapore, the government has previously implemented a 50% tax credit for firms that would employ energy consultants (Valentine, 2016)

4.3.2.3 Main overall implications

Transition to a CE seems to rely on government planning that reaches beyond the perhaps more immediate approach of innovation financing. As explored in this section (Table 3), non-financial capabilities are fundamental to bridge environmental and institutional pressures on EI implementation towards a CE. On one hand, policy instruments can promote customised training of personnel and decision-makers in firms raising the skills needed to engage in CE innovative activities. On the other hand, authorities can focus on facilitating access to expertise through consulting and assistance in problem solving. This can include instruments that encourage firms to seek professional assistance in adopting CE practices or promote business trips and workshops that allow the dispersion of innovations and knowledge resources to flow within and between innovation systems.

4.3.3 Network capability

As covered in the above sections, financial and non-financial measures can be incorporated in policymaking to increase eco-innovation processes and related CE practices. However, such policies are not primarily concerned with the conditions that promote the interplay amongst the various players in the system. Collaboration and network processes are important aspects of innovation systems and eco-industrial development (Robins and Kumar, 1999; Cerceau *et al.*, 2014; Patala *et al.*, 2014; Zhu *et al.*, 2014; Wang *et al.*, 2015; Geng *et al.*, 2016). Authorities can make use of policy instruments that aim at improving network capabilities and system complementarities in order to accelerate the transition to a CE (Valentine, 2016; Taddeo *et al.*, 2017). According to the literature analysed, we propose a separation of the instruments that contribute to this policy goal into two main sub-categories (Table 4): 'connecting network policies' are measures directed at relating different actors and facilitating their interaction within the system (creators, users, producers) by building, for instance, stronger social networks, information sharing platforms or coordinating innovation activities; 'geographic network policies' refer to the instruments that facilitate the physical relation and material exchange between operators across wider regions or promote the clustering of firms in eco-industrial parks (EIPs) to reduce barriers in the exchange, transformation and use of by-products.

Table 4: Summary of network capacity policies (own elaboration).

Scope	Policy focus	Instrument	Examples in literature
Connecting network	Social-oriented	Cooperation programs;	EcoSTAR
	Information-oriented	Information sharing platforms	Information databases; ICT platforms to facilitate resource allocation
Geographic network	Proximity policies	Planned coordination	Subsidies for relocation of suitable firms
	Distance policies	Logistics support	Transportation of wastes to recycling centres

4.3.3.1 Connecting network policies

As the corpus analysed stressed, inter-relatedness and cooperation between operators play a pivotal role in the adoption of CE practices. We identified two main sets of policy instruments that affect this function in innovation systems: social-oriented and information-oriented connecting policies.

4.3.3.1.1 Social-oriented instruments

Social-oriented policies aim at improving the communication and trust between operators in the network. As suggested by Dong *et al.* (2016: 398) in a case study of the industrial city Guiyang, China, "*in order to better promote the network development, a round table should be established so that all the stakeholders can meet each other and share different views, demands and technologies*". In the EU, governmental backed organizations called Innovation Poles integrating local IS networks and bringing together private entities, start-ups and research institutions "*with the goal of fostering local networking, providing high-value services, shared facilities for innovation, as well as addressing the major technological and strategic challenges to be faced by the local industrial community*" (Taddeo *et al.*, 2017: 8). Likewise, 'Symbio City', a conceptual framework for sustainable urban development emerging from Sweden, emphasises the role of social relations by focussing on capacity building between different stakeholders through sharing of experiences and knowledge, and serving as a basis for dialogue and cooperation, particularly at a local level (Liu *et al.*, 2014). In an analysis of different EIPs in the USA, Deutz and Gibbs (2008) highlight different strategies carried out by coordinators to encourage networking processes amongst tenants in EIPs including the participation of agents in education and promotion activities targeting the community, rewards for cooperation in rent reduction and a voluntary program that involves workshops, business meetings and by-product exchanges to advance sustainable business practices (EcoStar Program). In China, the government-backed TEDA Eco-centre, a coordination network with the objective of facilitating local IS practices, organises knowledge resources through meetings, on-site guidance, training courses and policy tours (Wang *et al.*, 2017).

4.3.3.1.2 Information-oriented instruments

Information-oriented policies refer to public intervention that has the objective of improving information sharing between network actors, often in association with information and communication technology (ICT) innovations that reduce information costs (Sterr and Ott, 2004; Reuter, 2016; Bai *et al.*, 2017). In a careful analysis on the components of eco-industrial networks, (Patala *et al.*, 2014: 173) hint at the importance of information sharing mechanisms when concluding that, while the building of the network itself requires "*comprehensive regional databases on the inputs and outputs of production plants*", the development of EI in this context depends on "*ongoing and planned technology development projects and platforms to pair firms with synergistic R&D opportunities*". Dong *et al*, (2014: 394) offer policy advise in this regard calling for the existence of a national IS technology inventory and stating that an "*information platform for the material/energy/waste exchange information publication is needed to be promoted in city and industrial park level* ". Sterr and Ott (2004: 957) defend that the need for ICT innovations in eco-industrial development is a function of geographical dispersion in the region as indirect communication across large distances "*reduces the quality of information while at the same time increases the costs of coordination*". Reuter (2016) underscores the importance of ICT solutions to enable the CE in metallurgy industries. Lewandowski (2016) highlights that information technologies and data management systems are important to support CE activities such as reverse logistics systems, material loops and reuse of components.

The implementation of such systems can contribute to assess the viability of transformation technologies as "*information about waste resource movements could support companies that are already implementing a waste-to-resource innovation, for example to construct confidence about resource availability*" (Velenturf, 2016: 128). As pointed out by Sterr and Ott (2004), the complexity of information sharing, on which the 'problem-solving competence' of a growing

IS network depends, can be addressed by publicly funded coordinating entities and ICT solutions. The latter could include waste management software that combine elements of geographic information systems with database management to "*optimize material flows in terms of costs, quantities, and transport distances*" (Sterr and Ott, 2004: 962). Dong *et al.* (2013) present a comparative analysis between EIPs at different levels of maturity and points out that in the Kawasaki Eco-Town project in Japan, an example of a highly developed EIP, authorities have "*established information platform through which the information about substance exchanges was shared with each participant with the help of government and the third party"* (Dong *et al.*, 2013: 236). In the Liaoning province, the Liaoning Clean Production Centre has implemented an information system that includes "*a database of cleaner production experts, a database of cleaner production regulations, and a database of cleaner production guidelines for different industrial sectors*" (Geng *et al.*, 2010: 1504), demonstrating that information systems can also be used to disseminate knowledge resources and relevant information on regulations.

4.3.3.2 Geographic network policies

The examined corpus stressed the importance of implementing policies that target the geographical distribution of actors within the system to promote the CE transition. In this respect, two distinct policy approaches were identified and termed as geographic proximity policies and geographic dispersion policies. Geographic proximity instruments promote the co-location of firms and other actors of the innovation system in pro-CE clusters. Alternatively, geographic dispersion instruments are related to the governmental actions taken to support industrial symbiosis (IS) relationships across wider regions.

4.3.3.2.1 Geographic proximity instruments

While the influence of public planning in the formation of clusters is a well matured academic topic – with notorious contributions from Michael Porter (Porter, 2000) – EIP configurations are distinct from conventional industrial clusters in that there is "*an awareness of the environmental benefits of agglomeration* [and] *an awareness of economic benefits in environmental practices*" (Deutz and Gibbs 2008: 1318). Geographic proximity in such settings increases the possibilities of developing synergistic and collaborative relationships of IS (Chertow, 2000), in particular in the exchange of low-value products (Chen *et al.*, 2012) such as cement (R. Kemp *et al.*, 2017), or by-products of challenging transportation like heat and steam (Deutz and Gibbs, 2008). This proximity also allows the exchange of tacit knowledge, i.e., knowledge that cannot be 'codified' or written down (Deutz and Gibbs, 2008; Velenturf, 2016). As in the celebrated case of Kalundborg industrial park in Denmark, EIPs can have their foundations in industrial exchanges of materials and energy between two or more firms that "*have spontaneously self-organized over the course of several decades without intentional plans and specific strategies*" (Korhonen *et al*., 2004: 299). While these economically viable collaborative engagements, often termed as 'low-hanging cherries' (Valentine, 2016), can take place spontaneously, information asymmetries or insufficient market pressures can make relocating operators into eco-industrial regions and the formation of *de novo* EIPs more challenging, justifying public intervention and planning (Deutz and Gibbs, 2008). For instance, in the Tianjin Economic-Technological Development Area (EcoTEDA), in Tianjin, China, the facilitating organization requested public support to attract firms through "*an active program of firm engagement that demonstrated the value of joining the program's network combined with financial and regulatory incentives, such as government subsidies for participation in the program database and use of an eco-logo*" (Anadon *et al.*, 2016: 9685).

The corpus presented several publications that developed and applied analytical tools or support models with the explicit intent of assisting policymaking and planning towards eco-industrialism (Van Holderbeke, 2002; Dong *et al.*, 2013, 2014, 2017; Geng *et al.*, 2014; Liu *et al.*, 2014, 2016; Nguyen and Ye, 2015; Yazan *et al.*, 2016; Zhe *et al.*, 2016; Ren *et al.*, 2016; Li *et al.*, 2017). However, there appears to be an ongoing debate about the effectiveness of planned design in local eco-industrial networks (Desrochers, 2004; Paquin and Howard-Grenville, 2012; Patala *et al.*, 2014). Broadly, the IS literature suggests two main avenues for EIPs formation with "*one strand of scholarship indicating that industrial symbiosis emerges spontaneously, through self-organization, and another strand supporting the idea that it is primarily a planned activity*" (Shi and Chertow, 2017: 3). Decision-making in planned eco-industrial networks involves planners or organisers that "*design the network by top-down planning and recruiting suitable companies*" whereas, when happening spontaneously, "*self-organised IS networks* (…) *emphasise community, shared values and embedded relations between actors, which enables the actors to find exchange opportunities*" (Patala *et al.*, 2014: 172).

More recently, a 'facilitated' approach emerged as a third perspective on innovation policies targeting eco-industrial networks that has been defended as "*a middle ground between self-organized and planned IS*" (Paquin and Howard-Grenville, 2012: 83). According to this strategy, participants should maintain their capacity to self-organise under a coordinating entity that can develop aspects of the network architecture from a broader perspective and mobilise new resources while interpreting the activities of the network for the wider society, influencing political decisions and forming new relations (Patala *et al.*, 2014). Furthermore, Paquin and Howard-Grenville (2012) defend that a facilitated network system that promotes a 'serendipitous' environment between tenants is likely to lead to "*the development of cultural embeddedness, as firm managers interacted and established relationships, developing interaction norms and, ultimately, trust*" (Paquin and Howard-Grenville, 2012: 90). In inter-organisational relationships, this 'embeddedness' *"allows a social dimension to exist, influencing the economic behaviour of partners*" (Adamides and Mouzakitis, 2009: 176).

Some authors from the corpus point to the important role of key influencers that represent the community and champion for trust and cooperation in a facilitated strategy for EIPs. These 'champions' are able to "*bring groups of actors together and motivate them to become personally involved in the construction of an EIP*" (Hewes and Lyons, 2008: 1339). Hewes and Lyons (2008) conclude that 'champions' should live and work in the EIP and be actively engaged in the community and that his absence compromises the long-term viability of the project.

It is common to find EIPs that begin with self-organised exchanges and evolve to increase their coordination and complexity of collaborations through facilitating measures that strengthen the network. For instance, the Kalundborg EIP, has its origins in exchanges that were not centrally planned but as the industrial park grew, it found support from governmental bodies to further develop symbiotic activities and new relationships amongst participants (Baldwin *et al.*, 2004; Valentine, 2016). IS practices in the Ulsan industrial complex region in South Korea also emerged spontaneously due to stringent environmental regulations and was later strengthened due to intervention from national actors at various levels (Park *et al.*, 2008). A third example comes from the sugar processing complex denominated Guitang Group, in China (Shi and Chertow, 2017).

Thus, as evidenced, policy intervention has a role in promoting CE practices in eco-industrial development. This can vary from central planning to a 'facilitated' approach that supports the network architecture and coordinates efforts while allowing tenants to self-organise.

4.3.3.2.2 Geographic distance instruments

Evidences from the corpus suggested that larger regional areas may build networks that are more suitable for closing material loops (Sterr and Ott, 2004). For instance, Bristow and Wells (2005) show some criticism towards the EIP approach, suggesting that it might represent a mere 'relabelling and rebranding' of previous sustainable practices adding that the concept "*subverts the hope and content of sustainability, reducing it to a slightly less wasteful form of 'normal' industrial development*" (Bristow and Wells, 2005: 176). These authors defend the adoption of 'regenerative eco-localism', a strategy for regional development based on the adaptation of businesses to local resources and conditions, niche exploration and diversity that contributes to the robustness of the system in a closer mimicry of naturally occurring ecosystems. In this perspective, eco-industrial networks could "*be dispersed both in terms of scale of capital, but also geographically*" (Bristow and Wells, 2005: 178). In an empirical study of Japanese Eco-Towns, Chen *et al*. (2012) conclude that agglomerated eco-towns do not exhibit advantages in their environmental performance comparing to dispersed eco-towns. The authors posit that while large recycling networks increase the market value for recyclables and, by extension, competition and investment, recycling networks may entail different spatial scales for different recycling materials. This may imply "*a multilayer symbiotic network within which, for example, organic waste and MSW recycling facilities function more at a local scale, while plastic, paper, and WEEE recycling facilities have a wider region for recycling*"(Chen *et al*., 2012: 139). The analysis showed some evidence of publicly-backed initiatives that aim at supporting wider networks. In the Eco-Town initiatives, public authorities have intervened to facilitate "*cross-prefecture transportation and transactions of waste exchange and information sharing*" (Chen *et al.*, 2012: 139) allowing innovative recycling projects to take advantage of existing industrial infrastructures in the region. In Taiwan, as part of the four-in-one policy mix, authorities have acted to provide logistics for recyclable materials across urban regions, namely glass wastes (Hsieh *et al.*, 2017). This grew the market for these residues which motivated private companies to invest in R&D and develop new applications for the recycled goods as new types of glass emerged.

Collectively, these evidences indicate that CE practices may benefit from regional eco-industrial development, in particular for material recycling. Policymakers can encourage related innovation activities by implementing instruments that facilitate the logistic and transportation of materials.

4.3.3.3 Main overall implications

As observed above, the CE implementation depends on the ability for actors in the system to form networks, exchange information, knowledge and ultimately material and energy resources, particularly in IS relationships. While inter-organizational collaborations in a locality can take place endogenously, it seems that these become limited after all evident and easily attainable cost-effective innovative efforts have been explored, thus hindering the potential of eco-industrial development. So, governmental action can contribute to develop IS and the underlying innovation activities beyond this point. According to the proposed categorization (Table 4), policy instruments can be designed to strengthen the connectivity and geographical features of networks. Connecting network policies focus on improving the social capabilities and the ability to share information within the network. The implementation of social-oriented policies, such as the creation of roundtables for stakeholders or platforms for collaboration, benefits communication between agents and facilitates knowledge transfer processes. Information-oriented policies include the creation of ICT platforms where the availability and price of by-products can be mapped to reduce information costs for companies within the network. This type of innovation is particularly important for industrial networks that cover wider regions in which direct communication is impractical. Geographic network innovation policies focus on the proximity of industries, bringing operators together to explore symbiotic relationships, or improve the conditions that allow eco-development efforts to take place amongst agents dispersed in a wider region. On the one hand, geographic proximity instruments, for instance financial incentives for new entrants or providing coordination for developments in EIPs, can lead to locally diverse industrial development, the exchange of materials and stimulate co-development of CE-enabling technologies. On the other hand, geographic distance policies may include support for transportation of materials in the region to encourage recycling related innovation activities.

The literature suggests a relationship between connecting and geographic network policies. For instance, inter-organizational relations taking place in close proximity are less dependent on information-sharing mechanisms to effectively reduce information asymmetries and may naturally share common perspectives for future developments (Sterr and Ott, 2004). Alternatively, wider regional level networks not only benefit more from such information policy instruments but may call for other policies that can assure the timely and cost-efficient transportation of wastes and resources (Chen *et al.*, 2012). Additionally, a 'facilitated' approach to eco-industrial development seems to benefit from social-oriented network policies to raise trust and cultural embeddedness between agents (Hewes and Lyons, 2008).

4.3.4 Increase demand

At the onset of innovation policy studies, scholars focused on increasing the emergence of innovations either directly through R&D policies or indirectly through intellectual property protection policies (Edler and Fagerberg, 2017). However, the 'holistic' perspective that emerged in recent years prompted a demarked shift in academic research and policy focus to incorporate aspects that affect the demand in innovation systems as well (Edler *et al.*, 2005; Edler and Georghiou, 2007; Iossa *et al.*, 2017). This section attempts to put in evidence policy strategies that aim at improving the adoption and engagement of public entities, firms or consumers at large, with EIs and "*by doing so, induce innovation on the supply side*" (Edler *et al*., 2016: 320). As suggested by the corpus, policies that intend to contribute to this component can target the increase of public demand or the increase of private demand for CE-enabling EIs (Table 5). Public demand policies generically refer to green procurement mechanisms. Private demand policies can be divided between market-based instruments and consumer awareness instruments. Market-based instruments refer to policies that render engaging with eco-innovations economically favourable and can be divided between the instruments that drive change through economic pressure such as taxes and tradable permits, and those that create economic incentives such as subsidies. Consumer awareness instruments aim at reducing information asymmetries between actors through measures such as labels and education programmes that raise awareness of the environmental benefits of eco-innovations over time. It is important to note that, while this section refers to policies that explore the demand for eco-innovations by lowering financial and information barriers to their development and adoption, there are other policy instruments that have influence in both the demand and supply, namely regulation policies such as bans or limits to pollution that will be explored in the next section (see Section 4.3.5).

4.3.4.1 Public demand policies

Public procurement schemes are an important component of innovation systems since it positions public bodies as "*buyers of innovation, either solely for their own use or in combination with private actors, to trigger a broader demand*" (Edler *et al.*, 2016: 320). In essence, public procurement refers to the effort that authorities make in acquiring goods or services, often through public tenders, which can be designed to evaluate certain characteristics of the solution other than its cost, such as its innovativeness (Edler and Georghiou, 2007; Edquist and Zabala-Iturriagagoitia, 2012). Sustainable or Green public procurement (GPP) is a terminology often employed to designate public procurement that considers environmental aspects in its selection criteria and has been suggested as a strategy to promote the CE (Witjes and Lozano, 2016). In this way, the demand for EIs can be directly incited by governmental authorities (see Edler *et al*. (2005) for examples). The corpus presented some examples of these instruments in practice. In the USA, the Environmental Protection Agency has published the

Table 5: Summary of demand increase policies (own elaboration).

Scope	Policy focus	Instrument	Examples in Literature
Public Demand	Public Procurement	Green public procurement	Procurement attending circular economy selection criteria
Private Demand	Economic disincentives	ETS and taxes on emissions and outward streams	Carbon tax; Carbon trading schemes
		Taxes on resources and inward streams	Severance tax;
		Tax on consumption	VAT and GST raise of disposable products
	Economic Incentives	Subsidies	Subsidies for biofuel
		Price premium	Feed-in tariffs
	Consumer awareness	Information campaigns	Education programmes; Public advertisement
		Eco-labels	Energy efficiency classification label

Environmentally Preferable Purchasing guidelines that "*specify products and materials that are considered environmentally friendly because of their recyclability, use of recycled content, and energy efficiency*" (Fiksel 2002: 25), whereas Executive Order 13123 instructs Federal agencies to "*apply the principles of sustainable design and development to the siting, design and construction of new facilities, and it also directs agencies to optimize life-cycle costs, pollution, and other environmental and energy costs associated with the construction, life-cycle operation, and decommissioning of facilities*" (Fiksel 2002: 25). In the Netherlands, although the government is obliged to opt for the most economically advantageous product (EMVI - Economisch meest voordelige inschrijving) in public tenders for infrastructure constructions, contractors that use green cements will be conferred with a better MKI (Milieukosten indicator), a single indicator that accounts for all environmental costs, which grants a virtual price reduction to their offer, thus increasing their competitiveness in these situations (René Kemp *et al.*, 2017).

4.3.4.2 Private demand policies

While increasing demand for eco-innovation in the public sector is important, policymakers may also have at their disposal other policy instruments designed to target private demand. Policymakers can make use of economic disincentives in the form of taxes and trading schemes, and economic incentives as subsidies and feed-in tariffs. The common rationale for these market-based instruments is to facilitate the internalization of externalities, i.e., to penalise or benefit a player for the negative or positive impact its activities have outside of its boundaries. At the same time, authorities can implement measures that intend to educate consumers and producers, and shift consumer awareness towards CE products and services.

4.3.4.2.1 Economic disincentives instruments

When applied correctly, taxes and tradable permit schemes can be a promising strategy to diminish poor environmental performance of private agents and shape markets to favour demand for eco-innovations that provide increased material efficiencies and sustainable business models (Dahmus, 2014; Meltzer, 2014). Taxes are commonly used by governments to induce distortions on the prices of goods or activities may not capture accurately all of the social and environmental costs, sometimes referred to as Pigouvian taxes (Pigou, 1920). As expressed by Koenig and Cantlon (1998: 27), when "*faced with unit price schedules on residuals, the constituent enterprises of the political economy are economically motivated to change the product and/or the processing technology, select alternative feedstocks, or modify product life cycles to reduce the risk*". For instance, a carbon tax that sets an extra cost to carbon emissions could prompt an industrial operator to acquire or develop pollution abatement technologies in order to keep its competitiveness. Because such measures could discriminate smaller companies with lower financial resources and thus investment capacity, governments have implemented emission tradable (ETSs), or cap-and-trade schemes. A limited number of these tradable pollution permits is issued by government authorities and distributed among polluting industries following predetermined criteria and can be traded between firms to better accommodate their financial capacity (Huisingh *et al.*, 2015). So, instead of investing in abatement technology, an industrial operator has the flexibility to purchase emission permits at market prices, which can turn out to be a better cost-effective option. As summed up by Huisingh *et al*. (2015: 10), "*under cap-and-trade regulations, firms may buy permits for production, or sell surplus permits, or buy and sell no permits at all, depending on the value of the initial cap. Under carbon tax regulations, firms are charged for their carbon emissions at a constant tax rate*".

The analysis allowed the identification of three major levels in which the application of economic disincentives can promote EIs and the CE. Firstly, as introduced above, taxes and ETS, can be effective mechanisms to induce the development and adoption of pollution abatement technologies and innovations. For instance, Lopes (2015: 818) states that these measures "*create an economic incentive to reduce emissions and the development of renewable and/or clean technologies*" while Huisingh *et al*. (2015: 10) point out that they constitute "*main* *approaches adopted by countries and regions to seek to achieve their emission reduction goals*”. In fact, as Lopes (2015: 832) argues, companies started to implement internal carbon pricing “*as a planning tool to help identify revenue opportunities, risks, and as an incentive to drive maximum energy efficiencies to reduce costs and guide capital investment decisions*”. Furthermore, Naims (2016) highlights the importance of these instruments to boost innovation activities in carbon capture and storage (CCS) technologies, stating that “*If the combined costs of capture, transport, and storage of a certain emitting source are lower than the CO2 tax or certificate price CCS will have a business case*” (Naims, 2016: 22239).

Secondly, taxes may be applied to create price distortions on the extraction and use of natural resources to appropriately shift the demand towards more sustainable options, as explored by the European Topic Centre Sustainable Consumption and Production and the European Topic Centre on Waste and Materials in a Green Economy (Silva *et al.*, 2016). These ‘severance taxes’ (Ge and Lei, 2018) may increase demand for waste-to-resources solutions, particularly in cases where “*resource prices only cover the related mining and delivery costs, but not environmental externality*” (Dong *et al*., 2016: 399). Low taxation on resources can hinder the circular economy as “*companies prefer to purchase cheaper raw materials rather than use recycled ones*” (Rizos *et al*., 2016: 4). Kuokkanen *et al*. (2016: 79) suggest that the recovery of nutrients from wastewater treatment plants to be used as fertilisers is thwarted by the government that is implementing overly restrictive waste legislations and permit systems, “*while at the same time not imposing any coercive regulations or taxes on mineral fertilizers*”.

A third strategy for taxes highlighted in the literature corpus relates to taxes levied on consumption. In this way, negative externalities associated to certain products are supported by the consumer instead of the producer to incite consumer demand for more sustainable options. This concept can be employed to facilitate product-service systems (PSS) by “*setting low consumption tax on PPS consumption while increasing the consumption tax of the respective conventional product*” (Laurenti *et al*. 2016: 392) or diminish the consumption of non-renewable materials by imposing “*additional higher taxes on the sale of all single-use one way material products using current tax mechanisms such as the Goods and Service Tax (GST) and Value Added Tax (VAT)*” (Silva *et al*. 2016: 231). Additionally, tax reform could implement “*lower/zero VAT for repair activities, second hand goods, re-manufactured products and products with a minimum recycled content* [, and] *tax relief for secondary raw material markets*” (Lazarevic and Valve, 2017: 63)

Several authors expressed the idea that tax collected funds should be used to finance subsidies and other public incentives. For instance, when arguing that businesses and individuals should be rewarded for their positive externalities, Avagyan (2017: 20250) asserts that "*fund for payments on this product must develop from the incomes of pollution taxes, etc.*". Huesemann and Huesemann (2008) points to a fiscal neutral approach that compensates carbon taxes with reduced income taxes. Lopes (2015: 832) defends that a pricing mechanism that channels revenues collected by carbon taxes to support clean energy R&D may be a "*powerful combination of improved economic dynamics toward sustainability*". In a more CE-oriented example, Laurenti *et al*. (2016: 392) suggest the use of these externality taxes to create "*subsidies for the development of necessary infrastructure, new businesses and markets to supporting repair services, reuse (reuse centres) and remanufacturing (take-back systems)*".

4.3.4.2.2 Economic incentives instruments

Public actors can further influence markets and create a demand pull for eco-innovations by introducing financial incentives or subsidy schemes. These incentives influence demand directly by lowering the adoption cost of EIs thus rewarding agents in the system for the positive externalities produced by their actions. Naturally, most of what was covered above regarding the effect of taxes can be inversed in the form of a tax reduction to attract demand. However, the literature points to specific examples of incentives applied not necessarily as tax exemptions or reductions but as subsidies. Renewable energies are found to be common targets of such policies and "*have been subsidized by guaranteeing prices that turn them into meaningful business solutions*" (Birat, 2015: 23). In Canada, for instance, the "*government will make available up to $1.5 billion for a biofuel application incentive*" (Avagyan, 2017: 20247). These subsidies can also be granted to promote recycled material uptake as it happens in Taiwan where authorities are able to keep glass manufacturers interested in buying recycled glass "*due to the subsidies they can receive by participating in the four-in-one resource recycling project*" (Hsieh *et al.*, 2017: 9). Feed-in tariffs, such as the ones based on the German Act on Granting Priority to Renewable Energy Sources (Werner and Scholtens, 2017), are a particular type of subsidies created to attract investment in renewable energy production in which producers receive a premium for each amount of energy produced. However, Werner and Scholtens (2017) conclude that, while the value of the subsidies in feed-in tariffs doesn't have a great impact on investment decisions, policy uncertainties drives investors away from projects.

4.3.4.2.3 Consumer awareness instruments

Consumer demand for innovations can be impaired by the information asymmetries, communication challenges and awareness deficits in innovation markets (Rennings, 2000). Authorities can implement policies that counter this limitation "*through information campaigns, awareness measures, labelling, support of standardisation and the like*" (Edler *et al*. 2016: 329), lowering informational barriers to adoption of eco-innovations and improving demand articulation between consumers and producers. In fact, from the consumer perspective, one main challenges that arises is that "*it is often difficult to identify the level of environmental performance of a product before purchasing it*" (Heinzle and Wüstenhagen, 2011: 60). The importance of such measures to unlock CE practices is put forward in the literature analysed. For instance, the relationship between information and consumer demand regarding closing nutrient loops in agriculture is very well illustrated in the study by Kuokkanen *et al*. (2016: 80): "*there is virtually no consumer demand for food produced with recycled nutrients, due to lack of knowledge and awareness*". On a similar tone, Xu (2016: 103) advances that low consumer demand for remanufactured and second-hand goods is attributed "*to the lack of positive publicity on the remanufacturing and consumer attitudes formed in a long term*". Tukker *et al*. (2010) highlights the impact that consumers have in sustainable consumption and production and that, therefore, should be targets of awareness campaigns to encourage engagement with CE practices. The crucial role of awareness oriented policies was also illustrated in the hybrid car market simulation carried out by Andrews and DeVault (2009). In their study, they conclude that while a moderate information campaign was not enough to cause major shifts, an aggressive governmental campaign that reaches every consumer increased the demand for this product significantly. Education of the general population about the environmental benefits of eco-innovations can also improve public support for government investments. In the Liaoning province of China where major top-down efforts have promoted cleaner production (CP), this has directed media agents to use their networks to inform the population of the program's progress including "*local television channels* [that] *were increasingly used to bring the message of CP into people's homes*" (Geng *et al*. 2010: 1505).

Eco-labels are other important mechanisms that can convey information about products such as the mandatory EU energy efficiency label for appliances and cars (Kaenzig and Wüstenhagen, 2010). Since most efficient products have a higher acquisition cost, it is important to implement mechanisms that create awareness for their long-term economic (and environmental) advantages. In a study on life-cycle cost, Kaenzig and Wüstenhagen (2010: 4) observe that "*an* *eco-label transforms the credence attribute* environmental performance[8] *into a search attribute by third-party certification, which guides consumers' investment decisions*". Moreover, aside from informing the consumer about intangible characteristics, eco-labels "*may provide a value in themselves (value function, e.g., prestige)*" (Kaenzig and Wüstenhagen, 2010: 4). In India, a label called 'Ecomark' was implemented by the government to help consumers identify environment-friendly products (Yaduvanshi *et al.*, 2016). Lazarevic and Valve (2017: 66) suggestion of disclosing "*information on expected lifetimes, repair and upgrade options; free access to repair and service manuals; access to safety data sheets for recyclers; product passports*" reinforce this policy trajectory towards improved consumer awareness to drive demand for CE products and practices.

4.3.4.3 Main overall implications

Overall, demand focused innovation policies appear to have a significant role in changing consumption patterns in favour of circular economy practices while stimulating eco-innovation activities. These policies can feature market-based instruments such as taxes and incentives but also instruments of a more regulatory nature such as public procurement or eco-labelling (Table 5). As explored above, green public procurement can create significant public demand for CE solutions since it positions governments as important market players – in the EU, public procurement is responsible for 14% of the GDP[9] – thus supporting eco-innovations involved in closing material loops, increasing resource efficiency or shared consumption solutions for instance. On the other hand, market-based instruments such as taxes, tradable permits and subsidies can be implemented and designed to create the economically attractive conditions that influence private demand towards circular economy models. Taxation on inward (material extraction and uptake) and outward streams (emissions and waste) can prompt operators to seek efficient methodologies, waste/pollution abatement technologies or waste-to-resource solutions in order to decrease their tax expenditures while subsidies can offer direct support for the uptake or production of recycled/renewable materials and clean energy. Tradable permits, such as the carbon ETS, are creative market-based solutions that can create an extra incentive to pollution abatement as the unused permits can be sold at market prices. Furthermore, the literature suggested that taxes can be important tools to sustain PSS by relieving taxes on services and raising taxes on products, particularly unsustainable products such as single use plastics and

[8] Emphasis in original quote.
[9] https://ec.europa.eu/growth/industry/innovation/policy/public-procurement_en

packaging. It is also suggested that taxes collected from unsustainable activities can be used to invest in R&D of waste-to-resource or create incentives for ‘circular’ business models. Finally, governments can implement measures that promote environmental education and circular economy awareness. Firstly, informed users may opt for pro-environmental products that represent long-term savings, even if facing high acquisition costs, such as in the case for domestic solar panels or high efficiency appliances. Information about the products reliability, repair and recycling options can also make products more attractive as a long-term investment. Secondly, educated populations can be more comprehensive or even appreciative towards stringent policies, public spending and investments in environmental causes which is indeed critical for politicians.

4.3.5 Regulation and Standards

Regulatory instruments are one of the main tools authorities use to help shape social and economic systems (Smith *et al.*, 2005). Public regulation and its relationship with competitiveness and innovation in firms is a topic that has attracted great academic and private attention (Mickwitz *et al.*, 2008; Blind, 2012). In general, regulation can be defined as “*the implementation of rules by public authorities and governmental bodies to influence market activity and the behaviour of private actors in the economy*” (Edler *et al*., 2016: 361). The imposition of these ‘rules’ can have positive impact in engaging agents with CE related EI activities (Dajian, 2008) and is often associated with the implementation of targets, bans or standards in a command-and-control approach or it can be more flexible as in the case of voluntary certification schemes (del Río *et al.*, 2010). As such, the range of regulations is understandably wide, and its taxonomy may present different configurations depending on the perspective that the researcher attempts to highlight.

Based on evidence from the literature, this section covers those instruments of regulatory nature that shape framework conditions of the innovation system contributing to the transition to a CE paradigm. We propose a division of this instruments in three main types of regulations, according to their targets (Table 6): products, processes and the institution framework itself. The first two types follow a stricter command-and-control approach: regulation on products may stipulate quality and design specifications or the application of mandatory post-sale services (e.g. warranties) while production regulation focuses on defining limits for the environmental performance of the process or determine the technology employed. The last sub-category focuses on regulations that build and strengthen features of the institutional framework. This includes support for intellectual property regimes, certification schemes and other voluntary programmes, stipulating practices for groups of players in the system, and providing definitions that are crucial to increase cooperation at different levels.

Table 6: Summary of regulation and standard policies (own elaboration).

Scope	Policy focus	Instrument	Examples in Literature
Product	Product composition	Targets for recycled materials uptake	Biofuel % in fuels
		Bans or restrictions in use of certain elements or chemicals	RoHS, REACH
	Product design	Mandatory standards for design for dismantling, repair, upgrade, etc.	Ecodesign Directive
	Post-sale services	Product warranties	Extended product warranty
Process	Performance standards	Performance targets	Material and energy efficiency targets; recycling targets
		Bans or limits on outward streams	Ban on by-product landfill
	Technology standards	Mandatory adoption of technologies	BAT
Institutional	IP protection	Period of economic exclusivity	Patent schemes
	Environmental certification	Issue standards voluntary standards	EMAS, ISO 14001
	Framework conditions	Waste management	EPR/IPR; PAYT
		Efficiency-oriented public services	
	Indicators and metrics	Reference inventories	LCA/GHG inventory
		Feedback mechanisms for framework definitions	By-product criteria

4.3.5.1 *Product policies*

As the analysed corpus stresses, product regulation encompasses policies that focus on the characteristics of the products themselves, allowing governments to contribute to the sustainability of products introduced in the market directly (de Medeiros *et al.*, 2014). The literature points to three main aspects of product regulation that fall in line with a EI-CE transition that will be discussed in the next sub-section: targets and bans for substances, product design standards and post-sale services associated with the product.

4.3.5.1.1 Product Composition instruments

Product regulation may stipulate targets for certain component in the constitution of the product. For instance, the composition of fuels is often regulated by governments to include a certain percentage of biofuels. As Avagyan (2017: 20247) points out, in Canada, one of at least 64 countries that have implemented biofuels mandates and targets, "*the Canadian Renewable Fuels Regulation set a content of 5% renewables in gasoline and 2% in diesel fuel or heating oil*". Wilts *et al.*, (2016) argue that stipulating a minimum content of recycled material in the manufacture of new products can benefit the recycling market. They highlight the success of the Californian Rigid Packaging Container Law that mandated resource consumption for manufacturers by design change and incorporation of plastic waste (Wilts *et al.*, 2016). Authorities can also implement regulations that seek to limit or ban hazardous substances from products. For instance, in some countries, particularly in the EU, some elements such as heavy metals have been limited by the Restriction of Hazardous Substances (RoHS) directive (Ogunseitan, 2007). Likewise, in Europe, some chemical substances are regulated by the Registration, Evaluation, Authorisation and Restriction of Chemicals regulation (REACH), an EU policy measure that controls the use of several hazardous substances and is revised every five years to assess the risk of new chemicals introduced in the market (Grundmann *et al.*, 2013). This regulation sets standards for product manufacturing "*so that only those chemical additives may be added that do not cause problems in a sustainable closed material and substance cycle*" (Grundmann *et al.*, 2013: 5). These regulatory measures can therefore have a great impact in advancing CE practices. Firstly, composition targets for products can be designed to specifically include recycled materials, inducing its demand in markets. Secondly, bans and limits on substances may incite the development of eco-innovations in the form of new sustainable products that comply with the regulation.

4.3.5.1.2 Product design instruments

Public authorities can further implement policies that determine standards for product design as a crucial step to facilitate recycling of products (Kovanda and Weinzettel, 2017). As Wilts, von Gries, & Bahn-Walkowiak (2016: 10) point out, although there is "*virtually no experience with standards on reuse and repair*", the European Ecodesign directive implemented mandatory Ecodesign standards that seek to increase product efficiencies, primarily energy efficiency in the use phase, yielding positive results in the phase-out of incandescent light bulbs. As such, these authors suggest that policymakers widen the scope of the European Ecodesign directive to include standards for the ability to reuse and repair products. They argue that those directives can be expressed, for instance, in the "*number of bolts, the avoidance of glue or welding of parts and the availability of spare parts*" (Wilts *et al.*, 2016: 11). Lazarevic & Valve (2017: 66) support this view suggesting the use of product policies that include "*the extension of eco-design regulations to non-energy related products and the inclusion of material efficiency, mandatory requirements to design for repair (e.g., ability to replace batteries)*". Furthermore, Xu (2016: 104) proposes the application of improved standards for remanufactured goods since in its absence "*most of the enterprises do not construct corresponding quality control system in the key aspects such as old part testing and repairmen of manufacturing blank, resulting in the lack of scientific guarantee of product quality*". As such, standards that define product design characteristics may stipulate the presence of certain features that contribute to their dismantling for recycle, repair or upgrade, adding to their circularity. Moreover, when applied to assure the quality of remanufactured products, standards can have an important role in building confidence for potential buyers. Lastly, product design standards may stipulate properties concerning the use phase of products such as their energy efficiency, increasing their sustainability.

4.3.5.1.3 After-sales instruments

Lastly, authorities can implement policies that stipulate mandatory after sale services. One crucial example is the provision of warranties that guarantee a period of free repairs or even substitution for the customer (EU, 1999). Not only warranties may serve as a marketing strategy for brands but its application is aligned with the CE as it promotes the extension of the lifetime of products and increases the perception of product value for consumers, particularly when applied to remanufactured or second-hand items (den Hollander *et al.*, 2017). Although this topic is not explored in detail in the literature here analysed, Lazarevic and Valve (2017) suggest an extension of the minimum legal product warranty period. This strategy may have a significant impact for the CE, being considered a useful way to reduce the life cycle impact of dishwashers in a report elaborated by the European Commission (Ardente and Talens Peiró, 2015).

4.3.5.2 Process policies

Standards and regulations may also be implemented to determine specificities of production processes. In this way, authorities can favour sustainable production processes over damaging practices and increase the demand and supply for eco-innovations such as efficient machinery. The literature points to two main avenues for regulatory actions and standardization in production processes: performance criteria and technology criteria (Bergquist *et al.*, 2013).

4.3.5.2.1 Performance standards

Performance standards are stipulated parameters that industry actors must comply with to safeguard their environmental performance. These standards do not focus on the technology involved in the process, allowing operators to choose the best cost-efficient option to comply with the regulation. For instance, in Sweden, the 1969 Environmental Protection Act defined several performance standards that regulated "*emissions to air, water pollution, noise and other disturbing activities from industrial plants*" (Bergquist *et al.*, 2013: 12) on a case-by-case licencing basis which, according to the authors, contributed "*to substantial environmental improvements at a low cost*" (Bergquist *et al.*, 2013: 17). Velenturf and Jensen (2016) found that the renewable obligations scheme, under which obligations for environmental performance begin at a low level but are successfully more stringent over time, were important drivers for waste-to-resources innovations in a case study carried out in the UK. Other example concerning clean production efforts taken in the Liaoning province in China, Geng *et al.* (2010: 1504) report that the cleaner production parameters are defined for each city by public authorities and include "*the annual total energy efficiency improvement indicators, the annual indicators for water saving and emission reduction, as well as the annual total amount of reused or recycled industrial solid wastes*".

Stricter regulation on production processes may also impose bans on certain practices that can stimulate innovative solutions. In the Netherlands, a ban on landfilled by-products from coal burning and iron industry created better conditions to incorporate these into sustainable eco-cements, thus innovating the construction sector alongside circular economy principles (René Kemp *et al.*, 2017). Another example from China illustrates how the phase-out of carbon tetrachloride from industrial processes, following the Montreal Protocol agreement, has stimulated innovative alternative methodologies for synthesis of methyl chloride (Matus *et al.*, 2012).

In brief, performance standards can tackle sustainability problems at different levels and phases of the supply chain. These standards can be expressed as, for instance, limits to resource uptake or water consumption, efficiency targets for energy and limits for end-of-pipe pollutants released in outward streams. As such, these policy instruments can drive agents to engage in EIs activities that enable CE practices.

4.3.5.2.2 Technology standards

In contrast with the performance standards explored above, technology standards establish the use of specific technologies that are regarded as the most sustainable option for a designated industrial context. For instance, to tackle industrial pollution in coordination between all members, the European Directive 2010/75/EU on industrial emissions (EC, 2010) proposes an integrated approach that targets "*emissions, waste management, accident prevention and energy efficiency, and on the application of best available techniques (BATs) and related technical guidance*" (Watkins *et al.*, 2013: 34). Establishing technology standards can have positive effects as seen with the EcoWater research project on improving the economic and environmental performance of water systems at the meso-level (Angelis-Dimakis *et al.*, 2016). The industry stakeholders involved in the project agreed that "*the implementation of eco-innovations in the industrial sector can be more easily promoted if the technologies are included in the corresponding Best Available Techniques (BAT) Reference Documents*" (Angelis-Dimakis *et al.*, 2016: 205).

In this way, policymakers can promote CE practices by establishing standards favouring innovative technologies that are resource and energy efficient, less polluting or contribute to waste-to-resource solutions. Moreover, because these standards are revised periodically – the Best Available Technique Reference Documents are revised every 8 years (EC, 2010) – it can be argued that implementing this regulatory instrument could stimulate investment in the development of technological improvements with the objective of becoming the reference technology. However, implementing technology standards carries the risk of increasing the path dependency of a technological regime and it may disregard the heterogeneity of contexts that firms operate, particularly SMEs, obstructing the develop and adoption of other cost-efficient 'circular' solutions (Bergquist *et al.*, 2013).

4.3.5.3 Institutional policies

In addition to the standards and regulatory instruments that focus on products and processes addressed previously, the analysis outlined another set of regulations that focus on the institutional framework as a whole. These policies cause a direct influence on the activities, relationships and interactions carried out by several actors in the socio-economic fabric such as consumers, public entities, private operators, researchers, oversight agents, etc. The data analysed allowed us to define four major areas that are governed by institutional regulation. Firstly, the protection of intellectual property, one of the earliest instruments devised by policymakers, is explored. Then, this sub-section will focus on voluntary certificates, useful to boost the image and environmental performance of private actors. Finally, the focus will be on regulatory framework conditions and metrics and indicators. While the former determines sustainable practices that actors must comply with, for instance, regarding waste management, the latter focuses on providing important definitions that help increase innovation related CE practices, compare results and allow products to circulate between operators in the system.

4.3.5.3.1 Intellectual property protection

As discussed in Section 2.3, externality issues associated with innovation development poses great challenges for policymakers, particularly in the case of EIs (see Section 4.3.1). Intellectual property (IP) protection is an institutional instrument that guarantees a designated period to exploit the created knowledge for the creators and those who invested resources in the process. As Anadon *et al.* (2016: 9686) argue, the IP regime allows "*inventors to exclude others from using patented technology for a fixed period, during which they can charge monopoly prices for patented products or earn revenues from licensing*". Additionally, in their study of eco-industrial networks, Patala *et al.* (2014: 172) point out that, in an IS setting, co-development of integrated solutions and knowledge sharing can actually be promoted by engaging in "*shared intellectual property rights and technologies to strengthen relationships between network actors*". However, in a study surveying experts from different EU countries, access to IP was considered one of the least important interventions out of the 24 functions of innovation systems surveyed (Hodgson *et al.*, 2016). Anadon *et al.* (2016: 9687) also offer some criticism stating that the IP regime "*restricts the use of new knowledge by raising prices or blocking follow-on innovation*". Highlighting the implications of this instrument from a globalization perspective, the authors further add that "*the increasingly globalized IP regime will diminish prospects for technology transfer and competition in developing countries, particularly for several important technology areas related to meeting sustainable development needs*" (Anadon *et al.*, 2016: 9687). Furthermore, Harmsen (2014) argues that open-innovation is an important driver for the co-development of innovation activities in sustainable industrial processes towards IS solutions.

In sum, IP regimes can have a positive impact in instigating EI activities. By establishing a period of commercial exclusivity, it creates an incentive for agents to develop new technological innovations that can contribute to material closed-loop cycles, particularly in IS settings. Still, such measures can raise the cost of access to innovative solutions and, consequently, hinder domestic and international knowledge transfer, burdening developing countries. Moreover, in contrast with the open-innovation mindset, over protection of IP may harm cooperative innovation and prevent the patented knowledge to be worked upon by others eventually wasting the ingenuity potential of the original creation.

4.3.5.3.2 Environmental certification

Other type of institutional regulation, identified in the corpus, is the environmental voluntary certification scheme. To get the certificates, candidates must prove compliance with standards that lay down "*the requirements which companies need to meet to achieve third-party certification*" (Robins and Kumar, 1999: 88). Although these certifications are voluntary, it is acknowledged that joining these audit schemes increases the firm's competitiveness, decrease their expenditures and increase innovation activities (Rennings *et al.*, 2006). To facilitate compliance, firms may incorporate the standards in environmental management systems to help them plan and establish the required practices accordingly (Rejeski, 1999). The European Eco-Management and Audit Scheme (EMAS) and the ISO 14001 are well known standards included in environmental management systems to define such criteria (EMAS, 2014). In this way, these schemes grant "*a third-party guarantee of environmental 'excellence', which is able to give an advantaged position (with respect to their competitors) to those organizations that, by adopting EMAS or ISO 14001, commit themselves to improve the environmental performance*" (Iraldo *et al.*, 2009: 1444).

The corpus pointed to some instances where applying for these certificates has contributed to increase the sustainability of firms (Cohen, 2006). For instance, Catulli and Fryer (2012) concludes that the uptake of ISO 14001 certifications is a relevant driver for the adoption of ICT-enabled low carbon technologies. Simpson (2012) finds that the ISO 14001 adoption is positively correlated with the positive effect that knowledge resources have in translating recycling pressures to firm environmental performance, "*which is not surprising considering the skill-enhancing nature of the standard*" (Simpson, 2012: 38). The corpus further revealed some accounts of implementation of environmental management systems and these standards at a wider scale, such as in the TEDA EIP (Liu *et al.*, 2016) and Ulsan EIP (Park *et al.*, 2008).

However, some scholars show concern regarding the implications that such certifications may have towards a wider industrial ecology and IS perspective. For instance, Korhonen *et al.* (2004) and Korhonen (2008) argue that, contrarily to the ISO 14001 and EMAS focus on the individual firms and organizations, a network approach to industrial ecology should consider the environmental impacts from an integrated perspective. Korhonen (2008) further questions whether pursuing 'eco-efficiency' (EE) standards at the firm level can impair the EE of the firm network in situations where wastes could be used as an alternative to fossil fuels in energy production. Thus, the author highlights the importance of defining the boundaries and scope of environmental management systems: "*If the system boundary definition is ignored, EE-orientated policy programs and management efforts may not lead to long-term commitment and action by the parties concerned*" (Korhonen, 2008: 1339).

In the end, it seems that voluntary certifications are a positive contribution to improve the environmental performance in firms. Nevertheless, the design of these instruments should keep in consideration the network context in which firms operate, particularly in IS relationships. Environmental certificates that focus on the individual level of firms may compromise CE practices that depend on the generation of wastes to be feasible, such as waste-to-resource solutions. It seems appropriate then, to establish a delimitation within which the industrial network and their effort to close material loops can be evaluated jointly for the purposes of attaining environmental certificates.

4.3.5.3.3 Framework conditions

Regulatory 'framework conditions' policies are governmental actions that pose a direct way to trigger CE procedures targeted to broad groups of actors such as industries or consumers (Wilts *et al.*, 2016). The extended product responsibility (EPR) is one of such policy instruments that aims at improving material cycles by extending the producer's environmental responsibility of their products to the post-consumer stage of their life cycle (OECD, 2001). Thus, it becomes in the producers' self-interest to design products that reduce waste after their use and/or make them easy to recycle, refurbish or remanufacture, encouraging other actors involved in the value chain of the product to change their behaviour as well (Wilts *et al.*, 2016). In Brazil, the Solid Waste National Policy implemented a shared responsibility for solid waste management policy that follows this mechanism (Campos *et al.*, 2014; Gutberlet *et al.*, 2017). Under this law, business sectors are responsible for the collection of their solid waste for reuse or recycling purposes, or its environmentally adequate disposal, through the Reverse Logistics system "*as a way of ensuring the return of the products post-consumption or post-sale*" (Campos *et al.*, 2014: 44). However, since it is organised by sectors, EPR expenses of similar end-of-life products are split amongst companies, usually based on the proportion of products they introduced in the market. Thus, if a company develops innovations that would reduce the end-of-life costs, it will share the rewards with the other competitors in the market, effectively facing a positive externality problem. In other words, producers would be more encouraged to introduce sustainable products if they can be responsible for the waste management of their own brand alone (Wilts *et al.*, 2016). As Wilts *et al.* (2016) recall, this individual producer responsibility (IPR) approach has been tested before and may be particularly beneficial for the management of waste electrical and electronic equipment.

Other policies can be employed to encourage recycling of household wastes (Ribić *et al.*, 2017). Pay-as-you-throw (PAYT) programs are one example of these policies that is attracting attention in the EU and worldwide (Yaduvanshi *et al.*, 2016). Following the polluter pays principle, PAYT aims at reducing waste by putting a charge on municipal solid wastes collected. In this way, domestic waste generators will have an extra incentive to reduce generic wastes and direct recyclable materials to the appropriate channel. Alongside other policy instruments, this measure is often applied in EU states, where some form of it is present all countries with recycling rates above 45% (EEA, 2016), to help them reach diversion from landfill targets (Silva *et al.*, 2016; Lazarevic and Valve, 2017).

One last example of regulatory framework condition policies emerging from the corpus relates to the implementation innovative schemes designed to increase the resource efficiency service providers. For instance, Schwager *et al.* (2016) highlights the joint efforts between the United Nations Industrial Development Organization and the Government of Austria that launched the Global Chemical Leasing Programme. Their goal is to promote Chemical Leasing business models with private partners (Schwager *et al.*, 2016). (Ness, 2008: 295) points to the "Save a Watt" programme, advanced by the United States of America public company Duke Energy, that rewards "*utilities for the kilowatts they save customers by improving their energy efficiency rather than rewarding them for the kilowatts they sell to customers by building more power plants*". This may inspire other private initiatives to develop creative business models such as Energy Service Companies that supply efficiency services to improve energy, water or materials efficiency making a profit out of the customer's savings. While not a policy intervention *per se*, because these companies and authorities share the same values, challenges and drivers, (Ness, 2008: 296) argues in favour of "*the need for an integrated policy approach to fully exploit their eco-potential*".

In sum, institutional 'practices' can promote innovation activities that may contribute to the CE transition. For instance, by transferring the responsibility of waste management to the manufacturers, EPR or IPR programmes can encourage the development of low waste products or firm supported recycled plans. PAYT schemes can put pressure on consumers to avoid unnecessary wastes and recycle contributing to achieving landfill diversion targets. Other public initiatives may implement new frames and business models for utility providers that reward efficiency over consumption.

4.3.5.3.4 Indicators and metrics

Lastly, based on the literature analysed, we characterise a fourth category of institutional regulation policies that aim at defining indicators and metrics for procedures inside and between socio-economic systems. As suggested by the evidence, we propose a separation within this category: first, we will cover the instruments that contribute to the standardisation of the different environmental assessment methodologies (e.g. to compare environmental performances of innovations or industrial regions); secondly, we highlight the public actions that define the rules for industrial permit granting (e.g. to allow the use of a by-product as a resource).

Measuring the CE and related EIs activities is central to eco-development and innovation systems (Smol *et al.*, 2017). Despite academic interest, the literature shows that there is a certain lack of consensus in finding standardised methods used to report performances or impact assessment. This was particularly true for measurements studies that included a performance assessment in IS settings, particularly at the EIP level. For instance, different emergy-based assessments were conducted by several authors to evaluate the performance in various eco-development regions (Geng *et al.*, 2014; Vivanco *et al.*, 2014; Ren *et al.*, 2016; Zhe *et al.*, 2016). The methodologies employed to measure carbon dioxide emissions also appear to lack a common agreement although it is common for authors to apply elements of a carbon accounting standardised protocol developed by the World Resources Institute and the World Business Council on Sustainable Development (Hoffmann and Busch, 2008; Shi *et al.*, 2012; Wiedmann *et al.*, 2016; Li *et al.*, 2017).

A trait commonly found in many of the above-mentioned research projects is the application of a life-cycle assessment (LCA) methodology that aims at accounting for the environmental impact of a product or process throughout its whole cycle. It is thus "*an effort to aggregate activities that are split among many industrial players (producers and end-of-life disposers) and consumers*" (Birat, 2015: 15). Because it represents a practical and pragmatic methodology that convert energy and material consumption to a single unit for comparability and totalling, often CO2 equivalents or solar emergy units (seJ), it is a tool widely used in ISO standards (Birat, 2015).With this purpose, authors may consult databases to obtain the conversion rates applicable for each item used in the computation. Regardless, because of its widespread use, it has received contributions from various users and researchers leading "*to fuzziness in methodological choices, which leaves much leeway to the practioners and, correspondingly, to results that can be difficult to compare between different studies*" (Birat, 2015: 15). Thus, while public institutions such as the EU publish LCA databases to support standardization[10], the literature analysis evidenced some concern towards the need for updates and maintenance of these inventories and a more comprehensive approach in LCA studies (Thomas and Graedel, 2003; Thomas *et al.*, 2003; Jones *et al.*, 2013; Birat, 2015). Other authors point to specific gaps in the databases and LCA research methodologies. For instance, Muñoz *et al.* (2008) make a case towards considering human excretion and nutrients lost in food preparation to improve LCAs analysis on foodstuffs while RISCKCYCLE project carried out by Grundmann *et al.* (2013) indicate that there is a worrying lack of information about chemical additives in LCA databases.

Institutional policies can also establish other metrics crucial for the innovation system, namely regarding the criteria used to define 'waste'. This issue is often highlighted in the literature, especially in the context of IS: "*When a material or substance flow is determined as a waste, its handling, including handling needed for waste utilization as a raw material or as fuel, is prohibited by environmental regulation and policy*" (Korhonen, 2008: 1340). This can result in diverted financial opportunities for producers as "*companies can do business with by-products whereas waste management only causes extra costs for them*" (Levänen, 2015: 542). To that, authors like Korhonen (2008: 1340) argue that the concept of waste is everchanging as it depends on the "*temporal context in which the definition is made*". Rizos *et al.* (2016: 4) also point to the consequences that the lack of a "*concrete, coherent, and strict legislative framework*" regarding waste labelling has for SMEs and the "*limitations on cross-border transportation of waste*". The European Waste Framework Directive (2008/98/EC) has been recognizing this issue and proposed a set of end-of-waste criteria to "*specify when certain waste ceases to be waste and obtains a status of a product*"[11]. These criteria have to comply with certain legal conditions, which in essence require that there is a demand for the substance that is under evaluation, its use complies with existing legislation and it doesn't lead to any overall adverse environment or human health impact. The criteria for the specific materials are then ultimately defined by the European Commission via committee procedure (also known as

[10] http://eplca.jrc.ec.europa.eu
[11] http://ec.europa.eu/environment/waste/framework/end_of_waste.htm

comitology)[11]. The Finnish Waste Act (646/2011) implemented the Waste Framework Directive in 2012 but in practice, the procedure to process and use residues is still very bureaucratic with several requests for permits that require approval from national and European authorities becoming a "*time-consuming and expensive process for all actors involved*" (Pajunen *et al.,* 2013: 150). Nonetheless, because the criteria are adjusted to the different materials that are put under consideration, this innovative approach allows for some degree of feedback between operators and policymakers, presenting an improvement over the previous legislation. As Levänen (2015: 548) defends: "*Institutional feedback mechanisms that are formal yet flexible are important "channels" for collective learning and for wider policy deliberation. Regulation that may be adjusted on the basis of the actors' experiences enables continual development of their ways of doing things*". Pajunen *et al.* (2013) highlights how national institutions such as the Finnish MOTIVA and the UK WRAP can interact with producers to facilitate the conversion from waste to resources. However, WRAP is depicted as more effective as it follows a market-oriented approach by producing quality protocols that safeguard the properties of the by-product and lower barriers to market entry: "*the key to building resource recovery networks is seen to be firmly in the ability to create and strengthen market confidence in residue quality standards and build networks to support utilisation of EoW residue streams*" (Pajunen *et al.,* 2013: 153). Thus, it seems that flexible policies that allow feedback mechanisms to facilitate the conversion of waste labelled materials to resources can improve the cycling of materials and the material efficiency of the system.

4.3.5.4 Main overall implications

As evidenced above, regulation policies are those institutional actions that set 'rules' upon which operators interact and engage in innovation activities. Drawing from the data, we propose a three-fold separation of these instruments (Table 6). Firstly, product regulation policies are instruments that mandate certain characteristics of products such as their composition, design or mandatory post-sale services. These can contribute to the CE by driving product innovation towards, for instance, the inclusion of recycled materials, ease of disassembly and repair or long-lasting use phases. Secondly, process regulations affect the production and manufacturing methodologies employed in the system. Instruments in this category include the stipulation of performance standards that define environmental parameters for industrial operators (e.g. CO_2 emissions), and technology standards that define best available technologies for determined industrial activities. Both these instrument types can be designed to promote CE practices: while performance standards can limit the uptake of virgin materials, pollution emissions and/or energy efficiency of industrial processes, technology standards can be employed to favour specific waste-to-resources methodologies. Thirdly, institutional regulations determine framework conditions, practices and metrics that encourage actors in engaging in innovation activities. For instance, IP protection instruments guarantee innovators an institutional right to their creations while voluntary certifications offer firms knowledgeable guidance towards improved environmental and economic performance. Other institutional instruments establish practices that affect the system and actors within it at a broader scale. For instance, EPR and PAYT programmes are both waste management practices that affect industrial operators and consumers, respectively. Finally, institutional regulation contributes to define important metrics and indicators in the innovation system such as the LCA databases used in assessment methodologies and the compliance criteria for permits that allow the introduction of residues back to production cycles as secondary materials. As suggested by the literature, the institutional regulatory instruments explored here can contribute greatly to the CE transition by optimizing the circumstances that lead to the emergence of EIs.

4.3.6 Foresight

Foresight activities are intimately related with policymaking, particularly with innovation policy. By its focus on support and boost the various innovation functions of the system to meet societal, environmental and economic demands, innovation policy is, by definition, a forward-looking activity (Havas *et al.*, 2010). Foresight assists policymaking by creating awareness and outlining future challenges and opportunities so as to incorporate those into the policy decisions taken in the present-day. In one of the most widely used conceptualization, foresight is defined as a "*systematic, participatory, future-intelligence-gathering and medium- to long-term vision-building process aimed at present-day decisions and mobilising joint actions*" (Gavigan *et al.*, 2001: V). In other words, foresight is a forward-looking policy activity that helps authorities in policy design through stakeholder engagement and knowledge sharing.

This topic has attracted great scholarly attention which spawned some overlapping conceptualizations (Weber *et al.*, 2009; Georghiou and Cassingena Harper, 2011; Ahlqvist *et al.*, 2012). Drawing from this debate, two main foci for foresight policy instruments can be identified (Table 7): evaluating and executing. The evaluating dimension aims at collecting information and identifying the major challenges and technology trends in close relation with stakeholders. This includes approaches such as horizon scanning or drivers/barriers studies (Habegger, 2010). The executing dimension focuses on bringing the actors together to create a common vision and influence the direction of future technology developments as well as fostering the conditions for disruptive developments to happen. It can be accomplished by instruments such as road mapping or scenario building (Habegger, 2010; Ahlqvist *et al.*, 2012). As such, foresight policies contribute to prioritise developments, plan future projects and predict scenarios, which are then incorporated in policy design and implementation.

Table 7: Summary of foresight policy instruments (own elaboration)

Policy focus	**Instrument**	**Examples in Literature (?)**
Evaluating	Identify critical challenges and opportunities;	Horizon Scanning in Europe bio-economy
Executing	counselling actors in decision making; mapping of avenues for development and improvement; strengthening of the network and build common view	Roadmapping in biorefineries Future scenarios in manufacturing

The importance of foresight to innovation policy extends to policies that are relevant to EI development and the CE, as evidenced in the literature analysed. In a characteristic evaluating exercise, Hodgson *et al.* (2016) perform a horizon scan to assess whether innovation policies mirror the needs and expectations of stakeholders in the European bio-based economy, with the objective of assessing "*regional differences with a view to focusing on areas of success and failure which could indicate best practices*" (Hodgson *et al.*, 2016: 519). Other evidences fall within the proposed executing dimension. May *et al.* (2016) conducted a focus group research with stakeholders concerning the future of manufacturing and eco-factories, seeking to "*spur debate in the research field and to identify important research areas from diverse perspectives*" (May *et al.*, 2016: 629). Similarly, Sautter (2016) presents the main considerations of the 'Manufuture' project, an EU-backed project that aimed at providing "visions, scenarios as well as [research, technology, development and innovation] strategies and roadmaps for the re-industrialization of Europe" (Sautter, 2016: 1). Also, Mohan (2016) applied the innovation policy roadmapping to the waste biorefinery industry, claiming "*it enables connection between multiple stake holders with diverging perspectives enabling them to align their actions toward shared long-term visions*" (Mohan, 2016: 82).

4.3.6.1 Main overall implications

As suggested by the evidence, foresight policies are relevant for the CE transition (Table 7). On the one hand, evaluation of previous and current experiences may help create a more realistic picture of the CE implementation and engagement of the various stakeholders, namely regarding technological, economic, social or institutional barriers or drivers. The collection of these experiences and knowledge highlights important challenges for the operationalization of CE and can help researchers and practitioners designing the way forward and create a common view for agents in the system. Of note, the identification of opportunities through these processes can also attract interest from entrepreneurs to develop pioneering businesses seeking first mover's advantages (Beise and Rennings, 2005; Cleff and Rennings, 2012).

5 Towards better 'circular' innovation policies

As proposed in the objectives of the present work, a taxonomy for innovation policy instruments was built using evidences from a literary corpus of policy-oriented academic publications focused on EI and the CE. A summary of the proposed taxonomy can be found in Figure 4. Overall, the wide range of instruments that policymakers have at their disposal can affect various innovation processes (creation, dispersion, adoption, etc.) contributing to an EI-mediated CE transition. The functions of the innovation system influenced by these instruments include supply and demand for CE-enabling innovations, network building amongst stakeholders to develop CE relationships, support to assist businesses in the CE transition and new business models, provide standards and an institutional framework suitable with CE implementation and providing an understanding of future developments and trends to better plan the transition ahead. The main implications for each core category were explored but, for the most part, the interactions between instruments when applied in policy mixes was not addressed. Here we discuss our results in light of the literature in general to contribute to the understanding of how the interplay of innovation policy instruments can advance the CE transition.

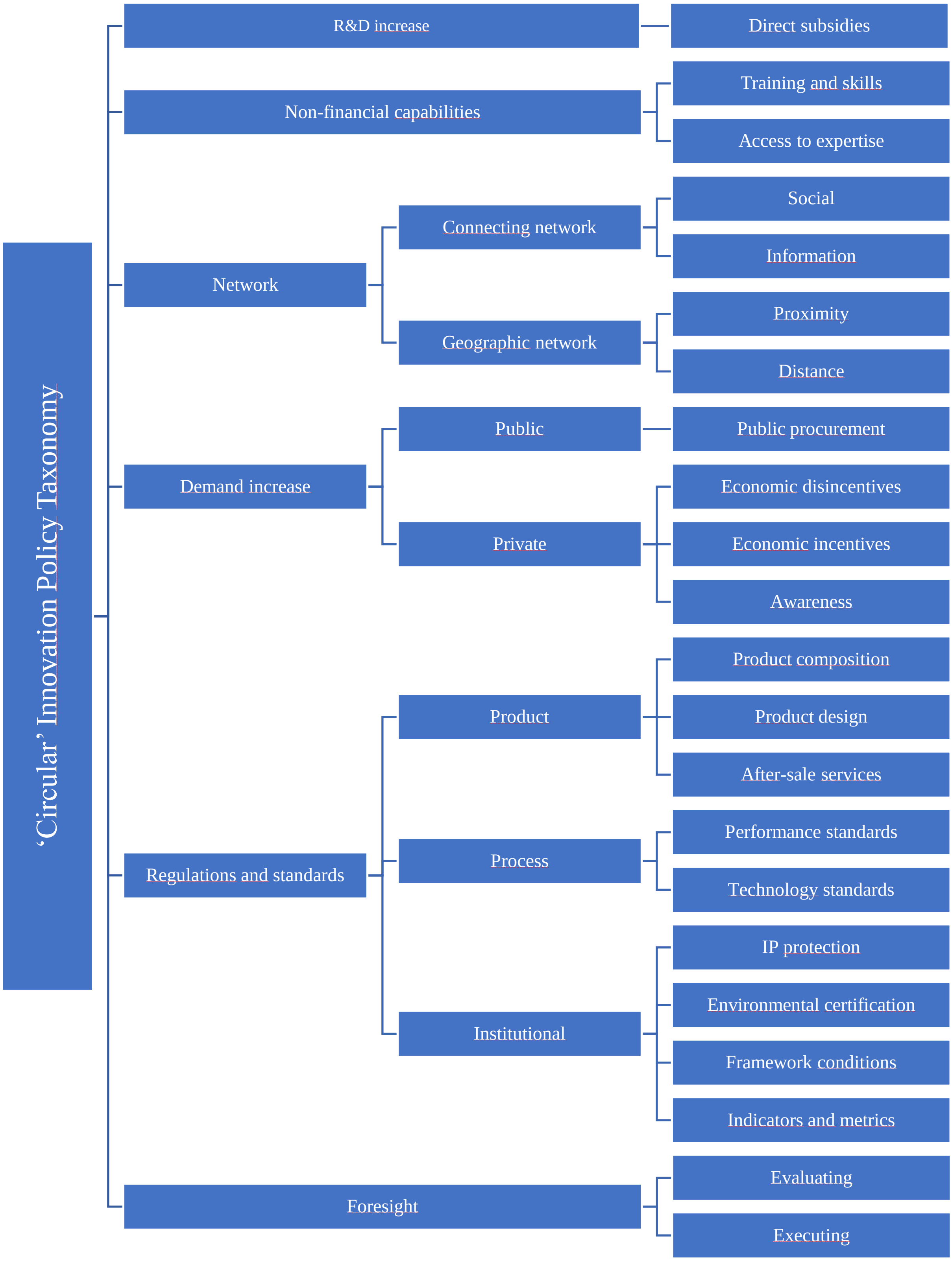

Figure 4: A taxonomy for 'circular' innovation policy instruments built according with the results from the literature review analysis (own elaboration)

5.1 An integrated view on 'circular' innovation instruments

Although categorisations as the one we proposed allow an individual look at the mechanisms of each instrument, it is important to consider policies from an integrated perspective. As addressed previously in Section 2.3, policymakers target innovation problems by combining instruments in policy mixes (Edquist, 2011). Thus, individual evaluation of those instruments disregards the complementarity and contrasting effect of the instruments in relation to the policy mix in which they are embedded (Borrás and Edquist, 2013; Fagerberg, 2017). Moreover, different instruments can be combined to induce a desired direction in innovation outputs (Newell *et al.*, 1999). As such, to encourage CE-relevant EIs, it is important to understand the complementarities of instruments in innovation policy mixes.

A review on our results can contribute to this discussion. For instance, as we addressed before in Section 4.3.4.2.1, different tax policies can be combined to create price distortions that influence CE practices at the consumer level (Huesemann and Huesemann, 2008; Silva *et al.*, 2016). A higher fiscal burden on the consumption of single-use products coupled with a tax relief in services and durable, recycled or refurbished goods can help to prevent waste production and incite shared consumption models in important industries such as the clothing industry and electronic equipment[12]. Other policy mixes can couple the phase-out of chemical components and pollutants with financing R&D to facilitate the technological shift (Yarime, 2007; Matus *et al.*, 2012). Moreover, because these subsidies imply a direct involvement with authorities, it gives them the opportunity to further steer the innovation effort towards circular technologies or programmes (Chen *et al.*, 2012). Another example could be using green public procurement as a mechanism to drive demand for circular technologies such as carbon capture and storage technologies (Naims, 2016) or nutrient recycling (Kuokkanen *et al.*, 2016) and implementing their inclusion in the best available techniques reference documents for relevant industrial practices (energy production, agriculture, etc) (Watkins *et al.*, 2013). One final illustration of policy complementarity can be the combination of minimum recycled content standards for plastic-containing products with the establishment of mandatory recycling quotas (Wilts *et al.*, 2016). This approach promotes the circulation of waste materials by inducing both supply and demand of recycled plastic which can prompt innovations in material and product engineering.

[12] In strategies such as these, Laurenti *et al.* (2016) suggest applying income levelling policies to avoid burdening low income households.

Certainly, as is crucial with policy mixes, other measures can be implemented to support policy complementarities. Taking the latter illustration above as an example, these can include product design directives that facilitate product disassembly or restrict the use of plastics with low recyclability value (Wilts *et al.*, 2016); municipal solid waste management policies that encourage plastic separation for households and provide proper logistic services (Silva *et al.*, 2016); network policies that facilitate information sharing and the transport of plastic residues; or awareness policies that implement campaigns in schools and firms to reinforce the important role that consumers have in sustainable transitions (Andrews and DeVault, 2009).

These examples are heavily based on our results and, on their own, are not sufficient to draw solid conclusions on how to combine policy instruments to best stimulate CE practices in general. Still, the observations suggest that, to promote an EI-enabled CE transition, policy mixes can target innovation problems at different stages of material cycles such as the value-adding transformations, transport, product design or use in service business models. In this way, combinations of complementary innovation policies can continuously encourage agents to engage with 'circular' innovations throughout the extending, closing and thinning of cycles, thus promoting the CE.

It is important to acknowledge that although we address situations where policies combine to create complementarities, regulatory and institutional factors are considered to be one of the main barriers to an EIs mediated transition to the CE (de Jesus and Mendonça, 2018). This suggests that the effectiveness of innovation policy mixes is dependent on other – if not all – policies implemented in the socio-economic system. While the interactions with other policies is beyond the scope of our work, the by-product criteria policy covered in Section 4.3.5.3.4 illustrates an institutional barrier associated with the legislation that regulates the utilization of waste labelled residues.

5.2 Environmental pressures, policy mixes and innovation outcomes

The impact that innovation policies have on innovation output may depend not only on the interplay of different innovation policies but also on multiple design features of the individual instruments such as stringency, firm discretion, flexibility or compliance periods (Carrillo-Hermosilla *et al.*, 2010; del Río *et al.*, 2010; Kemp and Pontoglio, 2011). The characterization of the various policy instruments carried out in this work support these observations, particularly for command-and-control instruments. For instance, stringency and short-time periods of compliance in performance standards may lead to elevated costs of compliance and adaptation but also prompt an increase in radical innovation activities (Yarime, 2007). Extended compliance periods and flexible regulations designed according to the technology conditions of the target industrial sectors may delay the implementation of a technological solution for the problem at hand but can decrease the adaptation costs for firms since they have more time to plan and select alternative innovation options (Yarime, 2007; Bergquist *et al.*, 2013). Additionally, progressively stringent targets (or increasing benefits) introduce predictability for the policy measures and a clear market signal for future innovation needs and opportunities (Yarime, 2007; Deutz, 2009; Bergquist *et al.*, 2013; Werner and Scholtens, 2017). The effectiveness of market-based instruments may also be improved by increasing stringency over an extended time period, such as progressively reducing the amount of ETS permits issued (Kemp and Pontoglio, 2011).

These observations suggest a relationship between environmental pressures, policy design and innovation outcomes. On one hand, environmental disasters (and social outcry) may pressure governments to implement strict policies that while effective in changing technologic regimes, represent elevated adaptation costs for industries (and political costs for governments). On the other hand, lenient policies may not stimulate radical environment improvements, encouraging agents to engage with low-cost incremental innovations that potentiate ‘lock-in’ issues. It can be argued that a compromise between overall costs and transition period can be attained by designing policies that represent a long-term commitment with increasingly stringent targets over-time, allowing agents to plan the transition ahead.

Understanding this relationship could benefit the EI-mediated transition to the CE. The transition to the CE is associated with radical innovations such as wastewater nutrient recovery stations (Brears, 2015) or innovative shared consumption business models (Lewandowski, 2016). Thus, policymakers should design instruments that balance the output of relevant innovation activities with the cost of compliance promoting the progressive phase-out of ‘linear’ technologies and implementing ‘circular’ solutions to the underlying environmental problems in due time. Failing to do so can lead to escalations in environmental and social pressures that could ultimately call for abrupt and costly policy interventions.

Our results point to the influence that other policy instruments may have in this balance. For instance, policies targeting access to expertise and awareness can enhance environmental performance of firms when facing recycling pressures (Simpson, 2012) and network policies can facilitate cooperation towards innovative solutions in eco-industrial settings (Hewes and

Lyons, 2008; Paquin and Howard-Grenville, 2012). The strategic niche management approach can also diminish the costs of radical techno-social transitions (Barrie *et al.*, 2017). Policymakers can thus combine the instrument design (stringency, predictability, etc.) with complementarities between instruments to drive CE-related socio-technological shifts in the most cost-effective and timely way for the components in the system.

It is important to note that most of the case studies observed here relate to relations between regulators and industries that took place between 1970-1990 (Yarime, 2007; Bergquist *et al.*, 2013) when environmental regulation was new. These authors acknowledge that in those early days it could have been relatively easy to adopt or develop pollution abatement technologies at reasonably low costs. The implementation of the CE can face significantly more complex challenges (Ghisellini *et al.*, 2016; de Jesus and Mendonça, 2018) and so more research on these relationships is needed.

5.3 Problem analysis and goal definition outline policy mixes

The direct objective of policy mixes is to solve the innovation problems in the system that contribute to the socio-economic grand objectives (Borrás and Edquist, 2013). To do so, policymakers can identify problems in innovation systems by means of ‘diagnostic analysis’ (Edquist, 2011). As such, governance over the transition to a CE through adequate goal-oriented innovation policy mixes should follow the identification of the inherent challenges and objectives.

Our results point to some instances of conflict between the goals expressed by the policies implemented, such as the criteria involved in environmental standards such as the ISO 14001. Because this standard focuses on material efficiency and reduced waste production, its design might hinder waste-to-resource opportunities, for instance, the burning of waste plastics to generate energy (Korhonen, 2008). This issue can be more evident for companies that integrate eco-industrial projects in which waste-to-resources is a central objective. One other example collected from our results debates the ‘circular’ benefits of concentrating operators in the same eco-industrial locality against the advantages of IS practices within wider geographic regions (Wells and Bristow, 2007). In this respect, authorities should first deliberate on what is the efficient size for eco-industrial developments to design policies appropriately (Sterr and Ott, 2004), particularly when considering recycling networks of different wastes (plastic, glass, wood, construction debris, waste water, municipal solid wastes, etc) (Chen *et al.*, 2012).

Some of the evidences analysed showed a strong focus on reducing pollutants in outward streams such as carbon emissions. It is important to note that pursuing these objectives alone may lead to EIs, thus improving environmental performances for polluting operators in line with sustainability values, but does not necessarily lead to reduced resource consumption or 'closing loops' (Geissdoerfer *et al.*, 2017). To induce 'circular' innovations in these cases, a comprehensive policy mix may be necessary to combine the goal of reducing carbon emissions with capturing and using atmospheric carbon. Still, such policy mix could give way to innovations that allow the captured carbon to be converted back into fuels at reasonable costs which would contribute to further the entrenchment of carbon fuel-based technologies such as the combustion engine in automobiles (Unruh, 2000). Moreover, this would not necessarily contribute to the reduction of the atmospheric carbon concentration that is believed to be at the origin of wide systemic environmental issues such as climate change and ocean acidification (Steffen *et al.*, 2015). Reduction of atmospheric carbon would need policies that depart from a resource-neutral discourse to encourage the innovation activities related with carbon capture and storage (van Alphen *et al.*, 2010). Although projecting these scenarios is beyond the scope of our work, it illustrates how defining socio-economic goals form a systemic view is at the base of innovation policy design. Implementing policies that address sustainability goals outside of a CE rationale might contribute to increase the challenges involved with CE implementation (technology 'lock-in') and thus warrants attention from authorities and policymakers.

This discussion stresses the importance of establishing goals to outline innovation policy. Because political processes are at the root of defining these goals, they might also differ between locations (Vorkinn and Riese, 2001), institutional dimensions (Bahn-Walkowiak and Wilts, 2017) and geographic locations (Konisky *et al.*, 2008). Moreover, environmental concerns inherently change over time as the impact of innovations and technologies is not always immediately intercepted (carbon emissions and CFC gases were once deemed generally safe) (Korhonen, 2008). Additionally, as illustrated by the NSI approach to innovation systems, policy mixes tend to get a distinct national 'flavour' (Fagerberg, 2017) reflecting the national institutional framework and its social, cultural and historical traits. Therefore, it seems inappropriate to replicate innovation policy success cases across the geographic and historical dimensions. Emulation of policy mixes requires interpretation and adaptation to the socio-technological context, innovation problems and goals of target systems. As such, innovation policy classifications like the proposed taxonomy should be regarded as a collection of evidence-based examples and not necessarily as a 'one size fits all' solution to achieve innovation related goals such as the CE problems.

5.4 Comparison with other taxonomies

According to our results, the innovation policies in general tend to follow similar patterns when addressing CE-enabling EIs. For instance, it was possible to use the simplified goal-oriented typology interpreted from (Edler and Fagerberg, 2017) as an initial categorisation of the evidences found in our work. However, when comparing our taxonomy to the complete typology proposed by these authors in (Edler *et al.*, 2016), some important differences have emerged. Two factors may justify these differences: firstly, while their typology considers innovation activities in general, our taxonomy is focused on EIs. This may have had implications regarding the instruments that resulted from our analysis. For instance, while innovation policies in general may include direct and indirect methods to increase firm R&D expenses (Kemp, 2011), governmental funding for EIs presented a much more directed approach (Chen *et al.*, 2012). Indirect R&D support may not be an efficient measure to increase CE related EI activities in the system since there is no particular stimuli towards CE practices. Secondly, our taxonomy focuses on the policy goals that enable the CE as opposed to innovation activities in general. Consequently, our data pointed to instruments that are not covered in other typologies because they relate to specific CE practices. This includes policies that target logistic services, transport of recycled materials, information sharing platforms to facilitate waste-to-resource practices and product definition regulations.

The evidences extracted from the corpus analysis contributed differently for the characterization of each of the six core categories. For instance, we found significantly more evidences that contributed to define regulation and certification policy instruments than we found to define R&D increase instruments. This has resulted in an asymmetric taxonomy with clear differences in detail and resolution between the categories. Such unbalance may indicate that the collection of academic research on the CE transition presents a bias towards some categories of innovation policy instruments. At the same time, it can reflect a limitation of the methodologies employed owing to terminology mismatch. Nevertheless, it can be considered that the taxonomy we propose does not provide a comprehensive look on instruments that support an EI-mediated CE transition. For instance, public demand instruments such as public-private partnerships, inducement prizes (Newell, 2008) or pre-commercial procurement (Georghiou *et al.*, 2014) are promising policy instruments in promoting EIs that were not explored in the CE-specific literature here analysed. Witjes and Lozano (2016) explicitly propose the use of Green Public Procurement to advance the CE but this publication was not intercepted in the systematic review[13]. Another important policy instrument for the CE that was not explicitly featured in our results is entrepreneurship support for 'circular' business models, despite it being a measure that is being currently applied at least in the EU[14].

Still, our results allowed us to take exploratory steps towards the understanding of the policy instruments underpinning a EI-mediated transition to the CE.

6 Conclusion

Acknowledging the importance and usefulness of comprehensive taxonomies with a strong emphasis on application and problem solving, the present work focusses on the analysis of an academic corpus to identify and explore the main innovation policy instruments with relevance for the CE.

An initial overview of the material gathered allowed the identification of some themes that affect governance as a whole. Firstly, the analysis showed that innovation systems benefit from reducing information asymmetries between regulators and firms in order to create policies that better comprehend the need to enact changes in the most feasible way. Secondly, policies can influence the nature of the innovations that result and contribute to lock-ins or create protected spaces that facilitate transition. Finally, the evidences contributed to the debate on the effectiveness of market-based instruments and a command-and-control approach to instil innovation activities.

Inspired in other innovation policy typologies, namely in Edler *et al.* (2016), the literature review allowed the identification and characterisation of the main EI policy instruments involved in an CE transition. Broadly, the taxonomy comprehends an analysis on policies that act in six major areas: 1) grow private R&D activities; 2) increase the access to knowledge resources and support; 3) strengthen the network capacity; 4) develop the demand for innovations; 5) implement regulations and; 6) lastly, carry out forward-looking analysis and actions to plan the transition.

Policy design and implementation is far more complex than applying one instrument and expect a corresponding effect. In that regard, the discussion of our results provided an integrated

[13]Regardless, the article is referred in Section 4.3.4.1
[14]http://ec.europa.eu/environment/funding/circular-economy-smes/providers_en.htm

perspective at policy mixes considering the effect of instrument design and interplay towards promoting an EIs-mediated transition to the CE. This gave way to the formulation of the following policy implications:

- Innovation policy mixes should seek complementarities between instruments that target different stages of material loops to continuously encourage agents to engage with CE innovation activities;
- Environmental policies should be designed with a systemic CE perspective from the onset, considering wastes as useful resources and refraining from using lenient anti-pollution regulation in isolation to diversify innovations and minimise technology 'lock-ins';
- Policymakers should design policies that represent long-term commitments and programmed stringency over time to provide unequivocal market indications of future innovation needs;
- Policy mixes should be attentive of the pertinence of overarching functions of innovation systems such as education, training, networking, or foresight.

Some caveats for this work are considered. Firstly, the material used to build the taxonomy was limited to publications from academia. While this yielded research-based evaluations of the policy instruments, our findings lack a contextualization from wider data sources, particularly from governmental institutions that may provide examples of policy mixes being used in practice. Secondly, the use of research descriptors carried the risk of exclusion and bias. This may have contributed to the asymmetric level of detail given to each core category in the taxonomy. Still, this observation can also be reflection of differences in the academic attention given to the different policy mechanisms under analysis. At the same time, the choice of keywords may be implicated in the noticeable amount of evidences focused on pollution abatement issues which, on its own, deviates conceptually from the CE. These limitations underline the need for critical judgment and further empirical corroboration of our findings.

Some future research avenues emerged from the present analysis. The proposed taxonomy is not comprehensive and lacked some evidences in key instrument categories. Therefore, some categories of instruments could be furthered as, for instance, education and awareness instruments, public procurement instruments or R&D support. Moreover, to test the strength and relevance of the proposed taxonomy, future research could include a comparative analysis with institutional innovation policy mixes such as the EU action plans for the CE (EC, 2015,

2018) or national programmes such as the Portuguese CE Action Plan[15]. Finally, future research could focus on the understanding of the relationship between techno-social transition pressures (environmental, social, political, etc.), the underlying optimal innovation output (incremental vs. radical; software vs. hardware), effectiveness of innovation policy (instrument design features; policy mix; supply vs demand; command-and-control vs. market-based instruments) and the aggregated costs implied in the transition (adaptation costs, political costs, oversight costs, etc.). We underscore the importance of evaluating the impact of ‘softer’ policy efforts in this balance such as education, access to expertise, facilitated approach to network building or strategic niche management strategies.

[15] http://eco.nomia.pt/pt/economia-circular/principios

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