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Note on the link between Circular Economy and technology-oriented theories of sustainable development: A literature review

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Nowadays, Circular Economy (CE) is one of the most popular notions among politicians, practitioners and academics. While several researchers indicate that the concept of the Circular Economy synthesises the major schools of thought regarding sustainability, no explicit analysis is available on the roots, theoretical backgrounds, and the novelty of CE or its understanding on the role of technology and innovation in achieving the goals of sustainable development. Based on a structured literature review, the goal of this paper is twofold: first, it aims to identify the main conceptual similarities and differences between the earlier technology-oriented concepts of sustainability and the Circular Economy, and secondly, it attempts to present how technological innovation is conceptualised in the Circular Economy. The main findings suggest that CE relies heavily on the previous theories of technology-oriented research streams, especially Blue Economy, emphasising the importance of innovation cascades and system innovation.

Keywords: sustainable development, innovation, circular economy, eco-efficiency, blue economy, natural capitalism, industrial ecology, bio- and eco-mimicry.

JEL codes: M29, O31, P4.

Introduction

In the last decades, several theoretical concepts have emerged that deal with the achievement of the different goals of sustainable development. Today, Circular Economy (CE) is one of the most popular notions among politicians, practitioners and academics (Brennan et al. 2015; Murray et al. 2017; Milios 2018). Theoretical and empirical studies on CE have grown exponentially (see Kirchherr et al. 2017) and the promotion of circular economy is now high on the EU and Chinese policy agendas, translating into a range of policy actions (Pardo et al. 2018; Ranta et al. 2018). While some authors (Ghisellini et al. 2016; Reike et al. 2018; Winans et al. 2017) stress the fact that the concept of CE has a long history, several researchers (Frodermann 2018; Korhonen et al. 2018a; Lacy–Rutquist 2016; Smol et al. 2017; Tonelli–Cristoni 2019) and the Ellen MacArthur Foundation (EMF 2012) state that CE synthesises the major schools of thought related to the technology-oriented theories of sustainability. The distinctive feature of technology-oriented views on sustainability, i.e. the concepts of eco-efficiency, bio- and eco-mimicry,

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natural capitalism, industrial ecology, the blue economy, is that these approaches attach a prominent role to technological development and innovation, albeit in varying degrees and ways. Although the concept of CE is defined as belonging to these approaches, in order to acknowledge its theoretical background and novelty, it is necessary to understand how technology-oriented theories view sustainability and the role of technology and innovation in achieving the goals of sustainable development. This paper aims to address these two challenges by investigating two research questions:

1. What are the main conceptual similarities and differences between the earlier technology-oriented concepts of sustainability and the Circular Economy?
2. How is innovation conceptualised in the Circular Economy?

To work towards answering these research questions, the paper has the following structure: the next section provides a brief summary of the circular economy, then the linkages between previous technology-oriented views and CE are identified by highlighting the targeted sustainability dimensions, key principles, tools and methods applied, and the role of technological innovation. Finally, key findings and arguments are summarised.

Definition of the concept of Circular Economy

Despite its popularity, there is no clear consensus on the meaning of Circular Economy in the literature. According to the report of the Ellen MacArthur Foundation (2012. 7), CE is "an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models." Based on an extensive literature review, Geissdoerfer et al. (2017. 762) define "CE as a regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling." Similarly, by analysing 144 CE definitions published in peer-reviewed journals, Kirchherr et al. (2017. 224) concluded that "CE describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operational at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations". By contrast, Korhonen et al. (2018b. 547) highlight that CE is a sustainable development initiative "with the objective of reducing the societal production-consumption systems' linear material and energy throughput flows by applying materials cycles, renewable and cascade-type energy flows to the linear system. CE promotes high-value material cycles alongside more traditional recycling and develops systems approaches to the cooperation of producers, consumers and other societal actors in sustainable development work". Accordingly, the three basic principles of circular economy are the preservation and enhancement of natural capital, the optimisation of resource yields by the maximisation of resource value over time in both technical and biological cycles, and the fostering of system effectiveness, which are ensured by the minimal use of raw materials and waste, the use of circular planning and production systems which supports the reintegration of products into the system at the end phase of their life-cycle, the use of new and innovative business models, the use of closed-loop material cycles, renewable and cascade-type flows, and the strong cooperation of producers, consumers and other societal actors (EMF 2012).

The central assumption of CE is that contemporary economic and industrial structures are linear by nature, preferring mass production and low production costs. These economic and industrial structures do not support the sustainability aspects of the economy and lead to the overuse of natural resources and raw materials as well as to the creation of a huge amount of waste. Therefore, in the concept of CE, the final consumption of goods must be based on a "functional service economy", in which the rental of goods replaces the sale of goods. Products should be designed and manufactured by using renewable natural resources whenever it is possible, materials should be cascaded across different applications until the end of their useful life, when materials must be returned to nature to enrich natural capital (EMF 2012). It is also emphasised that, while in biological cycles raw material and components can be safely returned to nature when reuse is no longer viable, in technological cycles, in order to preserve and maintain local resources, to eliminate wastes and negative environmental externalities, and to extend the useful life of products, prevention should be ensured by system thinking approaches through refuse, rethink and redesign strategies and reverse cycles whereby materials are conceived to return to the production processes through sharing, maintenance, repairing, refurbishing, remanufacturing and recycling (Potting et al. 2017).

A scientific consensus supports that CE and its mechanisms can be implemented at different levels, from a single company perspective to a value chain approach to the global economy. While, at the corporate level, companies can ensure a high level of circularity by applying circular design methodologies (green design, design for durability, design for reverse cycles) and reverse cycles and by developing innovative business models in which value propositions stimulate use- and result-oriented services (Tonelli–Cristoni 2019; Urbinati et al. 2017), at the regional level, cascade-type co-operations and collaborations across the different product chain actors and sectors should be encouraged and can be manifested in many forms: from information sharing through co-production to industrial symbiosis. At the macro level, activities from micro and meso levels are included and the macroeconomic impacts of these actions on the regional and national scale are investigated (Tonelli–Cristoni 2019, Frodemann 2018). In order to highlight how and from which disciplines of technology-orientated views these CE principles and mechanisms are originated, in the next section the linkages between previous theories and CE are identified in relation to sustainability dimensions, main mechanisms and principles, and the roles and preferred levels of technological innovations.

The comparison of CE principles, mechanisms, assumptions, and propositions regarding the role of technological innovation with the technology-oriented theories is conducted based on a comprehensive literature review (CLR).

The five-step process of CLR was structured as follows: 1. Scope definition; 2. Conceptualisation of the topic; 3. Literature search; 4. Literature analysis and synthesis; and 5) Research agenda. The literature sources used in this paper are the most widely accepted and cited works of major representatives of different theoretical fields.

Links to sustainability, key assumptions, mechanisms and principles of previous technology-oriented theories

The role of technology in minimising the negative environmental impacts (e.g. emissions, waste generation, extensive use of natural resources and raw materials) of economic processes is at the core of eco-efficiency studies (see Schaltegger–Strum 1989, Schmidheiny 1992, von Weizsächer et al. 1997). The OECD (1998. 7) defines eco-efficiency as "the efficiency with which ecological resources are used to meet human needs". Huppes–Ishikawa (2007) make a distinction between the analysis of value creation and the analysis of environmental improvements which can be combined with the inversion options. Based on this, they identified four fundamental variants of eco-efficiency: environmental productivity, environmental intensity, environmental improvement cost, and environmental cost-effectiveness. According to Schmidheiny (1992), key mechanisms for eco-efficiency improvements are minimising resource usage and negative environmental impacts and ensuring the availability of high-quality products and services for users. Eco-efficiency implementation levels include micro, meso and macro levels as well since eco-efficiency calculations can be used to assess and compare the performance of production processes, products, companies, sectors or regions, countries or macro-entities (Ehrenfeld 2005).

Industrial ecology (see Ehrenfeld 1997, McDonough-Braungart 1998, Hinterberger et al. 2003) argues that the negative environmental impacts of economic and industrial processes can be attributed to the fact that these man-made, artificial processes are open, therefore instead of enhancing eco-efficiency, new design principles should be defined, elaborated and utilised to support the integration of these artificial production and consumption systems into the natural environment, with production processes being designed from the beginning according to local ecological constraints. Thus, industrial ecology aims at creating closed-loop processes and transformation from simple linear material flows into a highly integrated system with closed cyclical material flows in which the waste serves as input from one process for other processes (Ayres–Ayres 2002; Graedel 1994). This also means that biological metabolism should be transposed into technical metabolism, i.e. into industrial material and energy flows. As Barros and Neto (2011) argue, the key assumptions and mechanisms of industrial ecology include the use of biological analogy and systems perspective, the necessity of technological change, the importance of corporate actions, dematerialisation and eco-efficiency and the use of forward-looking research and practice. Although industrial ecology studies usually focus on the corporate level, the control of production and industrial processes is also extended to inter-company, intersectoral or cross-sectoral relationships by emphasising the importance of industrial symbiosis. In addition, some authors (see Suh 2009) extend the scope of research by investigating regional and global material, energy, economic and even social flows.

The concept of biomimicry (Benyus 1997) assumes – by treating nature as a model, a measure and a mentor and by mimicking natural processes – that natural laws and logic can be adapted to human needs and complex problems, and innovative solutions can be found which inherently support sustainability. The theory simultaneously builds upon biological, design, natural, innovation, life, and technological aspects and the interrelations among them. The nine principles of life represent the central elements of this theory and serve as a basis for activities aimed to find solutions for the transition towards more sustainable production systems (McGregor 2013). The Biomimicry Design Spiral methodology (Benyus 1997), which can be used to guide product designers and other innovators through nature's reiterative design process, contains five steps: 1. Distil the design function; 2. Translate it into biological terms; 3. Discover natural models; 4. Emulate nature's strategy; and 5. Evaluate the design against the life principles of Nature.

Despite the fact that the biomimicry concept puts great emphasis on the bio-inspired solutions and represents an innovation process in which mimicking local flora and fauna is the key to developing eco-innovations, Marshall (2007) states that the theory of biomimicry only supports the use of incremental and radical innovations at the product level, focusing only on the environmental dimension of sustainability, and relying heavily on mass markets and experts. He also criticises the applicability of life principles by saying that the spiral design model follows the traditional model of innovation complemented with the step of searching for biological analogies. To eliminate these contradictions and shortcomings, eco-mimicry stresses the following aspects (Marshall 2007):

- Efforts should be made to develop local technologies that are socially and environmentally responsible and are inspired by the characteristics of the local ecosystem, flora and fauna.
- Nature-inspired innovations should be sustainable by nature.

• Nature-inspired innovations should support democratisation and localism.

• System thinking is necessary for designing bio-inspired local solutions.

Natural capitalism goes beyond the design and implementation of closed-loop systems by claiming the replacement of products with services and the investment in the natural capital of the ecosystem. The four key business actions of the approach involve the dramatic increase in the productivity of natural resources, the shift towards biologically inspired production models, the movement from products to solutions-based business models, and the reinvestment in natural capital (Lovins et al. 1999). In order to eliminate the wasteful and environmentally harmful use of natural resources, natural capitalism stresses that the product and process design activities of companies should rely on system approaches and the implementation of the whole system design should go hand in hand with the adaptation of environmentally friendly, eco-efficient technologies. Hawken et al. (1999) suggest that design activities concentrate on radically new, bio-inspired solutions and new business models building upon closed-loop material flows and zero waste. Instead of the sale of goods, new business models put the focus on problem solving. New models are initiated by the enhancement of the service intensity of products and product-service replacements, while value propositions rely on resource-efficient and closed material cycles.

According to Pauli (2010), the dominant economic model starts from the presumption of the principle of scarcity, coupled with unemployment, intra-generational inequity, waste, and by-product generation. Today's prevailing production and consumption systems are dominated and influenced by some multinational companies and their global supplier network. Furthermore, the linear processes of production and consumption systems neglect and ignore the potential synergies that lie in symbiosis and systemic thinking, and the development of these systems is guaranteed only by incremental innovations, and the process of decision making is cost and profit-oriented. Pauli (2010) also stresses that, in order to achieve the main goals of sustainable development, a new type of socio-economic system should be created that supports life, enhances flexibility, builds upon the existing goods and sustainable processes, operates according to physical processes, creates opportunities for learning, adapts to the continuously changing conditions, satisfies basic needs, develops the sense of responsibility, creates jobs, builds communities and provides multiple sources of income. The blue economy integrates the key principles of previous technology-oriented theories of sustainability, i.e. learning from nature, life-cycle analysis, zero-waste and emission, fit to local conditions, the substitution of something with nothing, the creation of locally contextualised systems, industrial symbiosis, and by using the concept of innovation cascades, blue innovations are in line with the concepts of system innovation theories.

Geissdoerfer et al. (2017) identified eight types of relationships between sustainability and CE and highlighted that CE is viewed as a condition for sustainability (conditional, strong conditional or necessary but not sufficient conditional relations), a beneficial relation (beneficial, subset or degree relations), or a trade-off in literature at the same time. While the first two major categories of relations support the concept that CE can be seen as a relatively new approach for the achievement of sustainability goals, supporters of the trade-off relationship between sustainability and CE argue that circularity and closed-loop systems can have costs and benefits in regard to sustainability, which can also lead to negative outcomes and foster certain aspects of sustainability, while lacking others.

Kirchherr et al. (2017) indicated that, in the relevant literature sources, social, environmental, economic and even time dimensions of sustainability were also expressed. However, based on the definitions examined, they found that CE's link to sustainable development was weak and that most authors saw CE as an avenue for economic prosperity, whereas previous scholars conducting narrative reviews of the CE literature had argued that CE would be mostly concerned with environmental aims. Nevertheless, Kalmykova et al. (2018) and Korhonen et al. (2018a) highlight that the social dimensions of sustainability should be also integrated into the concept of CE. These types of relations are not unique among the different technology-oriented theories, since the concept of eco-efficiency stresses the importance of the economic dimensions of sustainability by analysing the positive impacts of environmental and economic efficiency on corporate competitiveness. The explicit analysis of the social dimension of sustainability is also missing in the concepts of biomimicry and industrial ecology which emphasise the primacy of environmental and economic dimensions. Ecomimicry studies take one step further and deal explicitly with the local social impacts of nature-driven solutions. In natural capitalism and blue economy studies, economic, social and environmental dimensions have equal importance.

Regarding the key principles of CE (Table 1), it can be stated that, besides focusing on the negative environmental impacts of economic processes, CE builds heavily on the concepts of natural capitalism and blue economy by stressing that natural, economic and social problems are complex and interrelated and by incorporating the key principles derived from these research streams into its own framework and structure.

Table 1. Key principles of technology-oriented theories of sustainability

Research streams	Key Principles
Eco-efficiency	Pollution prevention, Cleaner production, Zero-waste, LCA, 3Rs
Biomimicry	Nature as a model, a mentor, a measure, Learning from nature, Nine principles of life, Bio-inspired design
Eco-mimicry	Creating locally contextualised systems, Learning from nature
Natural capitalism	Eco-efficiency, product-service replacement, investment in natural capital, Zero waste, Learning from nature, LCA
Industrial ecology	Cradle-to-grave, Cradle-to-cradle, Zero-waste economy, LCA, Closed-loop cycles, Industrial symbiosis, Learning from nature, Industrial symbiosis
Blue economy	Cradle-to-grave, Cradle-to-cradle, Zero waste economy, Industrial ecology and symbiosis, Learning from nature, LCA, Creating locally contextualised systems, Cascades of innovations
Circular economy	Pollution prevention, Cleaner production, Cradle-to-grave, Cradle-to-cradle, Zero-waste economy, LCA, Closed-loop cycles, 3-6Rs, Creating locally contextualised systems, Industrial symbiosis, Learning from nature, Cascades of innovations

Source: own edition

Sustainable development and the role of innovation

Theories and research studies emphasising the role of technological innovation in achieving sustainability are diverse in terms of the types and radicalness of the innovations they highlight. As for the type of innovation, according to the definitions of Hammelskamp (1997) and Kemp and Arundel (1998), eco-innovations include such new or modified products, services, processes, techniques, practices and systems by which the degradation of the natural environment can be avoidable, while sustainable innovations are composed of such new or modified products, services, processes, techniques, practices and systems which have positive social and environmental impacts. Regarding the scale and extent of innovation, as Tukker and Tischner (2006) and Carrillo-Hermosilla et al. (2010) illustrate, sustainable innovations can be classified as system optimisation, system redesign and system innovation. While innovations supporting system optimisation induce the incremental development of system elements without changing the structure of the incumbent socio-economic systems, system redesign needs incremental and functional innovations provoking the modification of subsystems and interactions among these subsystems within the existing boundaries of the system. System innovations are the sum of innovations appearing in the different dimensions of socio-economic systems that not only supports the appearance of new products and services but also allows a new system building on new logics, practices, and principles to be achieved.

Eco-efficiency theory (Yuang–Chen 2011) states that technological innovations are essential for the co-enforcement of economic and environmental aspects and stresses the importance of technological innovations supporting the reduction in the material and energy intensity of products and services and in the use of toxic materials, the recyclability of raw materials, the increase in the use of sustainable and renewable resources, the improvement of product life cycles, durability and the service intensity of products. While eco-efficiency studies emphasise the importance of the more innovative use of resources, incremental and sustaining innovations, other technology-optimistic authors (see Kemp 2008) argue that the development and diffusion of more radical and disruptive technologies are the keys to solutions. According to this theory, the main task of the state is to stimulate the innovation activity of companies, while companies are responsible for minimising the resource, emission and energy intensity of the production and service processes.

Industrial ecology argues that achieving the environmental, social and economic goals of sustainable development depends heavily on the innovation activities and efforts of companies. These innovations should not only target compliance with the regulation but also encourage the development and tracking of voluntary strategies (Doranova et al. 2012, Barros–Neto 2011). In this regard, different types of meso-level innovations supporting the appearance of industrial symbiosis are of particular importance, leading to (Doranova et al. 2012. 76):

• Environmental benefits such as improved resource use efficiency, reduced use of non-renewable resources and reduced pollutant emissions;

• Economic benefits such as reductions in the resource inputs costs in production, reductions in waste management costs and the generation of additional income due to higher values of by-product and waste streams;

• Business benefits such as improved relationships with external parties, development of a green image, new products, and new markets; and

• Social benefits such as new employment and raising the quality of existing jobs by creating cleaner and safer natural and working environments.

Although most of the literature sources on the theory of industrial ecology deal only implicitly with the potential role of society and the state in achieving sustainability goals, studies focusing on social life cycle analysis, social embeddedness (Boons et al. 2009) and the role and impacts of state interventions (Hendricks–Giannini-Spohn 2003, Green–Randles 2006) have been gaining ground.

As it was mentioned above, while the concept of biomimicry emphasises the role of bio-driven technological innovations at the micro level that sustains the key elements and interactions between these elements of the dominant technological system, Marshall (2007) states that an eco-mimicry strategy of innovation should be developed, with community members being involved in the definition of social, economic and environmental needs and in the preparation and execution of design projects. Local communities should be encouraged to identify the adaptability of strategies helping local animals and plants so as to solve problems in their life-worlds, to generate and execute ideas and problem-solving concepts based on natural solutions.

Similar to the theory of industrial ecology, business model innovations are at the core of the concept of natural capitalism. Tukker (2004) differentiates between product-oriented (product-related service, advice and consultancy), use-oriented (product lease, product renting or sharing, product pooling) and result-oriented (activity management/outsourcing, pay-per-service unit, functional result) services. In the first group, the business model is still geared towards the sales of products, but some extra services are added and business model innovations focus on the incremental and sustaining improvement of the eco-efficiency of services. The second category contains traditional business models which are not geared towards selling products, i.e. the product stays in the ownership of the provider, being made available in a different form and sometimes shared by a number of users. These business model innovations can be sustaining or disruptive by nature; however, the environmental gains related to them are limited. In the last group of product-service systems, business models build upon the agreement between the client and the provider on a result and there is no pre-determined product involved. According to Tukker (2004), in these cases, providers are motivated to search for radical and disruptive innovations which can lead to new service and system designs.

Even though Pauli (2010) does not give a clear definition for blue innovations, he implicitly suggests that, in the technology-oriented views of sustainable development, environmental innovations are emphasised, while innovations reinforcing the Blue Economy concept are considered to be sustainable ones. In this sense, eco-innovations are necessary but not sufficient to support the transformation of dominant socio-economic systems and draw attention to system innovations that have social, economic and environmental advantages, in which a new logic builds upon disruptive innovations using natural processes, fitting to local conditions, serving the principle of "substitution of something with nothing" and contributing to the change of one socio-technological regime to another. Blue economy stresses the use of solutions-based business models that promote the re-design of highly polluting industrial processes by incorporating the value of natural capital into business activities, replacing processes that use rare resources and high energy with cleaner technologies, and harnessing the power of cascading systems, where the waste flows of one process become the input of another (Tonelli–Cristoni 2019). New local creative and risk-taking entrepreneurs have a distinctive role in initiating, implementing and diffusing innovations. These sustainable innovations can generate income and induce new business models using wastes and by-products as inputs in a sustainable way. New socio-techno-economic systems rely on the network of new business models and support the revitalisation of communities as well. Blue innovations support the appearance of the desired socio-technological and socio-economic systems that build upon local resources and self-regulating closed cycles, utilise the principles of ecosystems and natural processes, support system-wide reconstruction and ensure the economic and efficient utilisation of wastes and by-products. According to Pauli (2010), the radical changes of social and customer behaviours, norms, attitudes, rules and habits are essential conditions for the diffusion of sustainable innovations since "ecosystems evolve towards ever-higher levels of efficiency and diversity due to contributions from all players" (Pauli 2010. 69), while "consumer enthusiasm and the desire of concerned citizens to contribute to solutions for sustainability can end up as an obstacle to embarking on real change" (Pauli 2010. 63). Innovations complying with the principles of the Blue Economy are ones that, due to their ripple effects, induce radical modifications and changes not only in the inherent structure of the existing technological systems but also in the interconnections among different technological systems with unique social functions. Only this can ensure that the waves of innovations in and out of a given technological system generate modifications in the different dimensions of the existing technological regimes towards social, economic and environmental sustainability.

Regarding the concept of CE, it can be stated that, similarly to the eco-efficiency theory, it supports the use of environmentally friendly incremental and sustaining innovations which help to reduce the raw material and energy intensity of the existing products and services, to eliminate the use of toxic materials, while contributing to the increased recyclability of raw materials and the use of sustainable and renewable resources and extending the useful life of products and services. This means that, as regards the types of innovations at the corporate level, product and process innovations appear in the form of circular supplies and resource recovery, remanufacturing, reuse, refurbish, repurpose, recycle and repair. However, the theory also emphasises that organisations have to redesign and rethink not only their products and processes but also their business models to become independent from scarce resources through renewability, reuse, repair, refurbishing, capacity, platform sharing, product service replacement, product life extension and dematerialisation (Boons et al. 2013, Urbinati et al. 2017). It is important to note that, regarding the stimulation of radical and disruptive business model innovations as system innovations at the corporate level, there is a strong parallel between the theories of natural capitalism, industrial ecology, system innovation and the Blue Economy concept.

With regard to the use of technology in product chains, Potting et al. (2017) distinguish three types of technological transitions, i.e. transitions in which the emergence of a specific, radically new technology is central and shapes the transition process itself while requiring socio-institutional changes, transitions in which socio-institutional change is at the forefront while technological innovation plays a minor role, and transitions in which socio-institutional change is central, but which are facilitated by enabling technology. They state that the common feature of these transitions is a change in the innovation direction from a linear to a circular application of materials, which can be promoted by incremental and radical innovations or the combination of both. Furthermore, literature on CE at the meso level stresses that, beyond intra-firm optimisations and innovations, inter-firm and inter-industrial optimisations are needed in the form of symbiosis, cascades of innovations or interlinked business models to achieve those socio-technical system-level transformations that are indispensable to the goals of sustainable development (Winans et al. 2017, Tseng et al. 2018). Macro-level CE studies and surveys also indicate that the state and its authorities play an important role in the implementation of innovations supporting the realisation of the circular economy by providing a supportive legislative environment, information, education, and platforms for discussions and by linking organisations to individuals, households and societal infrastructures (Droste et al. 2016). Society is also responsible for supporting new intra- or inter-firm business models since institutional innovations in its attitudes, routines and habits contribute to the acceptance and diffusion of new value propositions by companies and industries (Hobson–Lynch 2016). For a detailed comparison, see Appendices A and B.

Accordingly, comparing the different notions and propositions regarding the types, levels and roles of technological and non-technological innovations promoted by the technology-oriented views of sustainability, it can be concluded, that circular economy shares the view of the blue economy concept as it emphasises the following:

- Socio-technological regimes are composed of heterogeneous elements and actors, with local entrepreneurs being in an initiating position;
- The macro-level environment is the arena responsible for opening windows of opportunity and pressuring to search for innovative solutions;
- Technological regimes support incremental and sustaining innovation whereby new technological innovations appear in technological niches;
- Dominant technological solutions should be replaced with new innovative solutions based on the strategies of refuse, rethink, reduce, repair, refurbish, remanufacture, repurpose, recycle and recover;
- New market entrants and innovative business models have a spill-over effect on the actors and elements of the existing socio-technical system and value-generating processes;
- The development of a shared vision and networking should be supported by political institutions;
- Institutional innovations are essential for the transition process, but they can have negative and positive consequences as well.

Conclusions

As the literature review illustrates, despite the fact that Circular Economy has been interpreted as a new concept, its main principles and mechanisms can be found in the earlier technology-oriented theories of sustainability. Circular Economy uses and reinterprets the principles of Blue Economy and Natural Capitalism, with a deeper focus on corporate strategies and tools applicable in reverse cycles. It can also be stated that CE, just like the Blue Economy, is a mixture and rethinking of the earlier views of technology-oriented research streams rather than a radically new theory, which emphasises the role of system innovations in the transition to sustainable development.

A full examination of the advantages, limits and unintended consequences of the CE concept is beyond the scope of this paper. Further research is also needed to make an extensive and deeper analysis of theoretical and empirical literature on circular economy.

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Appendices

Appendix A. Key players and their roles in supporting sustainable development in the technology-oriented views of sustainability

Research streams	Role of the state	Role of society	Role of companies	Role of technology
Eco-efficiency Schaltegger–Sturm (1989), Schmidheiny (1992)	Support and stimulate corporate innovation activities	Not in scope	Minimise the material, energy and emission intensity of production and service processes	Technological innovations contributing to the enhancement of the eco-efficiency of existing models
Biomimicry Benyus (1998)	No explicit analysis or guidelines	No explicit analysis	Companies and experts have a key role in the development and use of nature-driven innovative solutions	Nature-driven technologies with lower negative environmental impacts
Ecomimicry Marshall (2007)	Establishment and support of local needs and circumstances, co-operations, support information flows	Local social actors and groups are responsible for participating in innovations fitting to local conditions	Companies and local actors have a key role in the development and use of nature-driven innovative solutions	Nature-driven technologies with lower negative environmental impacts and fitting to local conditions
Natural capitalism Hawken et al. (1999), Lovins et al. (1999)	Create and develop a supportive legislative environment, remove obstacles and support information flows	Generally, no explicit analysis In some cases: Social innovations are needed to accept product-service replacements	Investments in natural capital, use of innovations supporting eco-efficiency, creating new product-service models, use of biomimicry principles, redesign products into services	Technological innovations supporting product-service substitutions and the enhancement of eco-efficiency

Research streams	Role of the state	Role of society	Role of companies	Role of technology
Industrial ecology Ayres–Ayres (2002), Green–Randles (2006), Graedel (1994)	Role of the state is secondary and limited to creating and developing a supportive legislative framework	No explicit analysis	Priority of companies and other business actors in developing and using innovations that support the creation of closed-loop production systems	Technological innovations supporting the creation of closed-loop production and economic systems
Blue Economy Pauli (2010)	Promote local planning and design, local models and concepts leading to closed-loop flows and systems	Explicit need for social and institutional (attitudes, habits, routines) innovation and transformation	Initiating innovations with social, economic and environmental advantages, supporting industrial symbiosis, cooperative R&D projects and technological innovations	Nature-driven technological innovations supporting the substitution of "something with nothing"
Circular Economy Boons et al. (2013), Korhonen et al. (2018), Tonelli–Cristoni (2019), Hobson et al. (2016), Potting et al. (2017), EMF (2012), Droste et al. (2016), Frodermann (2018)	Create and develop a supportive legislative environment, promote education and collaborative platforms and give financial support	Implicit need for social and institutional (attitudes, habits, routines) innovation and transformation	Initiating innovations with social, economic and environmental advantages, supporting industrial symbiosis, cooperative R&D projects and technological innovations	Technological innovations supporting cascade flows, closed-loop economic systems and extending the life cycle of products at all levels

Source: own edition

Appendix B. Role of innovation in the technology-oriented views of sustainability

Research streams	System levels	Role of innovation	Type, degree, and scale of innovation	System analysis methods
Eco-efficiency Schaltegger–Sturm (1989), Schmidheiny (1992)	Macro: not explicit Meso: value chains Micro: Corporate level	Eco-innovations supporting corporate competitiveness	Product/service/process innovations, incremental and sustaining innovations, options for radical innovations, eco-efficiency developments at corporate level.	Only environmental impacts of innovations are examined through calculations
Biomimicry Benyus (1998)	Product/production levels	Nature-driven product and process innovations	Priority of product and process innovations, incremental and radical, sustaining and disruptive innovations.	Case study analysis of a given technological innovation
Ecomimicry Marshall (2007)	Local economy, Product/production levels	Nature-driven product and process innovations	Priority of product and process innovations, radical and disruptive innovations.	Case study analysis of a given technological innovation
Natural capitalism Hawken et al. (1999), Lovins et al. (1999)	Macro: not explicit Meso: Product-Service systems Micro: Companies	Innovations at product-service system level with environmental benefits	Product/service/process innovations, incremental- radical, sustaining-disruptive innovations. Innovations in a given product-market mix, in an industry or at the value chain level.	Case studies
Industrial ecology Ayres–Ayres (2002), Green–Randles (2006), Graedel (1994)	Macro: Regional, global material and energy flows Meso: Industrial symbiosis Micro: Corporate level	Importance of innovations appearing in a given production-consumption system and value chain	Product/service/process innovations, business model innovations. Incremental and radical innovations, subsystems of socio-technical systems in an industry or at the value chain level.	Input-Output models LCA models, green accounting

Research streams	System levels	Role of innovation	Type, degree, and scale of innovation	System analysis methods
Blue Economy Pauli (2010)	Macro: national, global conditions Meso: local, regional economy Micro: technological niches/companies	Blue innovations with environmental, social and economic gains, innovations in technological niches, business models, technological systems/ regimes	Product/service/process innovations, business model innovations. Radical and disruptive innovations, system-level innovations, regional and local economic impacts of innovations are stressed.	Case studies, dynamic system models, business models
Circular Economy Boons et al. (2013), Korhonen et al. (2018), Tonelli–Cristoni (2019), Hobson et al. (2016), Potting et al. (2017), EMF (2012), Droste et al. (2016), Frodermann (2018)	Micro (corporate), meso (industry) and macro-level (national/global) system perspective	Innovations with environmental and economic gains, innovations in business models, value chains, technological systems/ regimes	Product/service/process/ organisational innovations, business model innovations. Radical and disruptive innovations, system-level innovations, regional and local economic impacts of innovations are stressed.	Case studies, dynamic system models, business models

Source: own edition