Report on State-of-the-Art Research in the Area of the Circular Economy

A Part of Deliverable 2.1

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1 Introduction

The circular economy (CE) is one of the currently most discussed terms among environmental economic scientists and a focus of the European Union Horizon 2020 strategy. Its core defining element is the "restorative use" of resources. Raw materials shall no longer become discarded waste. "While great strides have been made in improving resource efficiency, any system based on consumption, rather than on the restorative use of resources entails, significant losses along the value chain" (Ellen MacArthur Foundation, 2015).

The CE is not the only highly discussed concept that implements circular ideas in economic activities. Many other concepts with circular ideas also exist, and the question arises of how these concepts can be differentiated. By clearly positioning the CE in comparison to other concepts, we can enable more consistent research on the concept and formulate comprehensive implementation plans. Concurrently, a comparison enables the identification of potential improvements to the current definition of CE if the research reveals that other adjoining concepts propose more useful specifications or provide additional aspects or tools that should be included.

Therefore, as one deliverable of the *R2π – Transition from Linear 2 Circular Economy project,* this research will provide a contemporary literature review of the CE and the closely associated concepts to formulate a common conceptual ground and understanding for advancing the project goals. This will enable the formulation of the working definitions and research ontology for the next *R2π* deliverable, thereby establishing a coherent basis for researchers to conduct further studies and allow practitioners to better understand how they can act within a CE.

During the past years, the term 'CE' has gained increasing attention (Lieder & Rashid, 2016). Because of the perceived urgency for better resource efficiency, academic articles and practical propositions around the concept of CE have increased significantly. Scholars agree that the CE stands in contrast to

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the linear economy based on a "take-make-dispose" sequence. However, the propositions mirror different understandings of what a CE entails (Ghisellini et al., 2016).

On the one hand, the concept of CE is often presented and perceived as an optimization of waste management only. Many researchers focus their work on technical aspects of the CE, such as material flow management or waste management. On the other hand, scholars argue that the CE stands for much more than waste management and entails the design of business models (Mentink, 2014) or even represents a framework for the whole economy. As such it should also include consumer behaviour.

The Ellen MacArthur Foundation, a charity and non-profit organization that strives to develop the framework of CE is one of its main advocates. The foundation encourages including aspects of other concepts with a circular approach such as: the blue economy (Pauli, 2010), cradle-to-cradle (van Dijk et al., 2014), closed loop supply chains (Bhattacharjee & Cruz, 2016), industrial ecology, reverse logistics (Agrawal et al., 2015), resource efficiency (Schandl & West, 2010), low waste production, biomimicry (Benyus,1997) and sustainability in a broader sense (Finkbeiner et al., 2010). However, even though these concepts often have overlapping ideas and similar goals, they also differ from each other with regard to certain characteristics. Using them interchangeably would thus lead to confusion and an unclear definition that is hard to operationalise. To avoid further confusion in the field, it is important to clearly define the concept of CE.

At the same time, practitioners in business and politics need a clear definition of what to aim for when deciding to progress towards a CE. The challenges are inherent in our linear economic system. While recycling can lead to cost benefits, it has often not been considered as a profit-generating activity. In developed countries, corresponding business models and economic benefits have often only been detected as a consequence of governmental regulations for waste treatment. Interestingly, repair, recycling and reuse have been much more of a business model in developing countries with limited financial means and less access to new products from industrialized countries. A transition to a

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fully developed CE, however, will also entail a systemic behaviour change, as has been shown for a country like India (Goyal et al., 2016).

While Ghisellini et al. (2016) provide an extensive review of CE literature, highlighting CE features, advantages, disadvantages, implementations and more, an extensive analysis of the literature only yielded one paper (Lieder & Rashid, 2016) that summarises existing concepts of circular solutions in a broader sense. However, they take the relatively narrow perspective of manufacturing processes. Because of the abundance of related terms (industrial engineering, cradle-to-cradle, etc.), some scholars even claim that the CE stands on “shaky ground” (de Man & Friege, 2016, p. 1). Our paper aims at closing this gap and overcoming the confusion between the current definitions of the CE and related concepts. It contributes to the differentiation of the CE from adjoining concepts while, at the same time, sharpening the concept by integrating useful ideas from these other concepts to offer a well-founded revised working definition for researchers, practitioners and policy makers alike.

2 Current definitions of circular economic concepts

The analysis is based on an exploratory literature research by which the main concepts in the field of a circular economy are identified and examined (Stebbins, 2001). Through this analysis, the respective characteristics of concepts are identified, providing a basis for comparison. During the first phase, the explorative concept analysis is achieved through a literature review. To identify the relevant literature, academic search engines (e.g. EBSCO and JSTOR) have been used for the primary source of literature. As keywords, the following terms have been used: circular economy, industrial ecology, closed supply chains or closed loop supply chains, cradle-to-cradle, reverse logistics, blue economy, performance economy, natural capitalism, biomimicry, and regenerative design. The resulting articles have also been used to identify further relevant literature. Thus, the method of concentric circles (Saunders, 2011) was applied with backward and forward oriented literature search in order to reduce the risk of overlooking prominent and important sources. Altogether, more than 300 sources have been identified.

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The following analysis highlights the most important characteristics and features of each concept. Characteristics that appear as key differentiators are identified in order to use them as a basis for the comparison between the concepts.

2.1 The circular economy

The roots of a concept for circular material flows reach back many decades. It has already been proposed by Boulding in his 1966 book, "The Economics of the coming Spaceship Earth." Boulding claimed that circular systems within the global economy are unavoidable in order to guarantee human life on earth in the long run. Other pioneers are Pearce and Turner (1989) who relied on Boulding´s ideas. They agreed that the traditional linear economy without recycling elements cannot be sustainable and consequently must be replaced by a circular economic system. For their reasoning, they referred to the second law of thermodynamics (Georgescu-Roegen, 1986) stating that the entropy of an isolated system will increase over time and, thus, devalue higher order energy or material. Focusing on the waste management policy aspect of the CE, its roots in Europe can be traced back to Germany where, in 1972, a waste disposal act was established (BGBI I, 1994). Germany also developed the concept of extended producer responsibility. These policies are considered first steps to promote the implementation of the CE (Andersen, 2007). Other inspiration for the CE can be found in the research on the industrial economy (Preston, 2012) and in general systems theory (Von Bertanlaffy, 1968), supporting the idea that an economy can only be analysed in a holistic, complex-systems thinking approach. Industrial ecology has been a further root for CE research concerning the analysis of industrial systems and operational optimisation which already illustrates that the currently discussed concept has been developed on the basis of other approaches.

One of the current recognized definitions of the circular economy is offered by the Ellen MacArthur Foundation (2016): "A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles." Generally, by defining the circular economy we are referring to a "closed-loop economy" (Wysokińska, 2016, p. 1) that "does not generate

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excessive waste and whereby any waste becomes a resource" (ibid., p. 1). Closed-loop means that all materials stay in a cycle and can continuously be reused. Waste, in the above definition, does thus deviate from the common understanding where it represents residuals that are dumped or treated but do not re-enter the production or consumption cycle. In a CE all substances have to stay within the system and "waste" may only exist in a form which is able to be reused. The call for its limitation thus corresponds to a request for more efficiency.

In addition, the CE is often interpreted as a new business model (Ghisellini et al., 2016) for a sustainable economy and healthy society. In many instances, the CE tries to incorporate several relevant aspects for sustainable development, i.e. social, environmental, economic and technological aspects (Ghisellini et al., 2016). The CE concept should be seen as an opportunity to transition the economy to develop new and different business models, where wellbeing is decoupled from resource consumption and environmental impact.

Furthermore, the CE addresses micro processes in companies as well as the macro level of the economy as a whole (Birat, 2015). Through its principles the idea of CE encourages all agents of an economy to contribute to a more environmentally friendly use of resources (Planing, 2015). Educated innovators and intermediaries and explicit decision-making tools for the CE are considered necessary to facilitate implementation (Golinska et al., 2015). Finally, the measurement of circularity is considered to play a crucial role, but there is no prevailing opinion on which operationalization to use. Instead, many different approaches are discussed. Most scholars refer to classic eco-efficiency indicators (Shou-feng, 2006) or to alternatives such as the "reuse potential" indicator of Park and Chertow (2014).

As Ghisellini et al. (2016) state, the CE is often misinterpreted as only "an approach to more appropriate waste management" (p. 2). This perception is enhanced through prominent principles like the 3Rs: reduce, reuse and recycle, often quoted to summarize the core approach of the CE. However, this waste oriented view of the 3Rs is far too limited for the CE. The true concept of the 3Rs within the

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CE encompasses a much broader perspective of the economic system, and they can play a larger role in its design and implementation in many other areas, beyond end of life waste. Furthermore, other definitions of CE are even broader and the 3Rs become only a general enabling framework. For example, the CE also may include a detailed regenerative aspect, which refers to the recovery of materials as well as the use of renewable energy solutions (Ghisellini et al., 2016; Ellen MacArthur Foundation, 2015; European Union, 2015). For the recovery of materials, a reclassification into technical and nutrient materials is proposed (ibid.). It pertains to two material flows: biological nutrients that can be reintroduced into the natural system and manmade technical ingredients that should be recoverable; not in a biological sense, but through industrial recycling mechanisms.

To understand the complexity of 3Rs concept embedded in the CE, we highlight each one of them in more detail. The first R, "reduction", represents the endeavour of material or eco-efficiency in production (DeSimone & Popoff, 2000) as well as the attempt to reduce inputs into the system through improved consumption processes. Eco-efficiency should be understood as a business framework and goal at the same time, aiming at "creating value while decreasing environmental impact" (Huppes et al., 2005, p. 1). Thus, two kinds of motivations are important for the CE: economic and environmental improvements. The social dimension is not referred to explicitly within the goal of eco-efficiency. However, a resource efficient production allows for the use of the saved resources for other purposes or to be saved for later generations. Resource efficiency thus indirectly increases social well-being (Ness, 2008).

The second R, "reuse", also implies a better design of products and business models for a cyclical "disassembly and reuse" sequence (Ghisellini et al., 2016, p.6). Stahel (2013) further argues that anything related to the principle of reuse, such as remanufacturing, repairing/fixing should best be conducted regionally, thus reducing transportation and packaging. However, the reuse principle can only be implemented successfully if consumers are willing to buy reusable and remanufactured goods. This requires additional marketing from the companies (Watson, 2008), further education of people

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by public institutions, and a shared responsibility between producers and consumers to collect products after the first cycle of use (Lenzen et al., 2007).

The third R, "recycle", refers to "any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations" (European Union, 2008, p. 8).

To summarize the principles of the CE, scholars agree that the CE needs to be a regenerative system. However, most work focuses on waste management as represented by a narrow interpretation of the 3Rs principles, although the principles propose more far reaching options for a CE.

2.2 Related concepts

Many researchers as well as practitioners use terms such as CE, cradle-to-cradle, industrial engineering or closed loop supply chains almost interchangeably. In the following sections the concepts are analysed separately, especially highlighting their main principles and potentially differentiating characteristics. The related concepts are presented according to their applicability to the characteristics that are presented later in the comparison of concepts.

2.2.1 Cradle to cradle

The concept was developed by the chemist Braungart and architect McDonough in their book "Cradle to Cradle – Rethinking the way we make things" (2002). The term cradle-to-cradle (C2C) has, however, been introduced already in the 1970s by Stahel. The concept of C2C aims at minimizing environmental damage of products through more sustainable production processes, distribution and disposal practices, and socially responsible products (Visser, 2010). Sometimes C2C is also referred to as a closed loop supply chain, where the end of life of a product leads to the recycling process (De Pauw et al., 2013). After recycling, materials are re-used for the same purpose or to produce different products (Huang et al., 2007).

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The concept not only includes the production and recycling system but also puts an emphasis on the design stage (Braungart et al., 2007). C2C design is inspired by the "biological metabolism" and tries to translate it into a "technical metabolism" of material flows in industrial systems (McDonough et al., 2003). Existing products shall be redesigned for increased efficiency to minimize negative effects of commerce. Components must be designed for circular recovery or reutilization. Thus, it is primarily a philosophy of design with two main categories of materials: technical and biological (McDonough & Braungart, 2010).

Lovins (2008) asks for the full elimination of waste. If "waste" is still created, it should be, again, a value-producing resource. C2C requires implementing collection and recovery procedures within the companies' own supply chains (Kumar et al., 2008). This point highlights the strong linkage to the research stream of reverse logistics. Renewable material and energy inputs are suggested to be used in production in a C2C approach (McDonough et al., 2003). Lastly, C2C embraces the ideal of diversity from natural systems, meaning that healthy ecosystems of communities and companies living symbiotically in close distance should be promoted in order to encourage local social responsibility. To support the implementation of C2C, in 2005, Braungart and McDonough established a certification process for companies working according to the C2C principles.

In summary, C2C is a holistic framework that aims at creating efficient, sustainable, and waste-free systems. Even though the application of C2C mainly occurs on the micro-level, the concept goes beyond manufacturing and design processes. It can also be applied to architecture and construction, urban environments, and infrastructure design and encompasses social criteria in its certification.

2.2.2 Closed supply chains

Closed supply chains (CSC), also described as closed loop supply chains, highlight the importance of circularity and are quite close to the idea of the CE. Product reuse and recycling are the two factors "closing the loop" (Savaskan et al., 2004). In addition, CSC contains discussions about how governance and coordination mechanisms may either facilitate or impede the development of circular systems (Sarkis et al., 2011). According to Krikke et al. (2004), CSC consist of both a forward and reverse supply

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chain where "a mix of reuse options" is employed by the producer depending on "the most profitable alternative" (ibid., p. 24). The concept thus encompasses an explicit profit orientation. The authors identified five business processes that are key for reverse side activities of CSC:

1. product acquisition through buy-back, or other physical collection methods;
2. reverse logistics including the transport of used goods to the location of recycling;
3. sorting and classification of returned goods into one of six reverse supply chains ("direct reuse, repair, refurbishment, remanufacturing, cannibalization, and scrap" (ibid., p. 25).);
4. recovery, ideally in the same supply chain, otherwise reuse in an alternative supply chain ("open-loop application" (ibid., p. 25));
5. redistribution and sale of secondary products in a "usual" forward chain.

The concept of CSC also includes four categories of product returns (Toffel, 2004), namely: reusable (e.g. packaging), commercial (e.g. warranty or product recall), end-of-life and end-of-use (e.g. after a lease) returns. The setup of supply chains should be chosen depending on the type of return. Besides the focus on the types of returns and their characteristics, the CSC discipline also stands out for highlighting the potential of modularity in products (Krikke et al., 2004).

Based on the idea of CSC, the supply loop framework claims to combine the concepts of CSC, IE, RL and the measurement from life cycle assessments. It thus represents an interesting tool and proposes a strategy "for end-of-life product management that creates economic *and* environmental value" (Geyer & Jackson, 2004, p. 56). A supply loop is only "closed" if the secondary resources are used for the same original product again. Accordingly, an "open" supply chain uses secondary resources for other products. The measurement of success of the implementation of supply loops should capture economic and environmental benefits (Ayres et al., 1997). Neto et al. (2008) present a framework that uses multi-objective programming to help optimise the design of efficient logistic networks, taking cost-related and environmental aspects into account. This represents a complicated but nevertheless very useful tool to both design and evaluate the logistical aspect of CSC.

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2.2.3 Industrial ecology

The science around industrial ecology (IE) has been established in 1989 when Frosch and Gallopoulos published their seminal article "Strategies for Manufacturing". They argued that "an industrial ecosystem" (ibid., p. 1) should be implemented globally to attain an integrated and environmentally sustainable model for industrial activities. This industrial ecosystem should optimize the use of energy and materials, minimize pollution and waste, and consider the environmental impact of every (by)product of a manufacturing process. Starting with their article, the field received international recognition - beyond other reasons - through the renowned *Journal of Industrial Ecology*.

Typical for the field is the examination of the interplay of technology and industrial activities, as well as environmental and societal consequences (Erkman, 1997). This examination can take place on the local, regional or global level by analysing the usage and flow of materials and energy during the product life cycle in order to reduce environmental damage. Waste management plays a central role in this concept and should be used as an energy or material source (Frosch, 1992; Ghisellini et al., 2016). IE has three dimensions: analytic, methodological and proactive. It is analytic because IE tries to understand "how the industrial system works" (Erkman, 1997, p. 2). Secondly. It is methodological because IE wants to include regulation within the industrial system and its "interaction with the biosphere" (ibid., p. 2). IE is proactive (Berkel et al., 1997) as it provides ideas for governments and companies alike about how to contribute to a more sustainable economy. Other authors, such as Allenby (2000), are dedicating their focus to the necessary policy frameworks to implement IE and want to provide an easy-to-follow handbook for practitioners (Ayres & Ayres, 2002). Strictly referring to the name of the concept, IE seems to be limited to industrial processes.

To summarize, IE takes the perspective of a biological ecosystem to examine industrial processes (Allenby, 2000) and aims at restructuring industrial processes for compatibility with the natural ecosystem. As Geyer and Jackson (2004) conclude, IE focuses on the environmental aspect of new strategies instead of the profitability.

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2.2.4 Reverse logistics

Reverse logistics (RL) is another term in connection with circularity. The European Working Group on Reverse Logistics, REVLOG, defines it as "the process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal" (de Brito & Dekker 2004, p. 5). It primarily relates to the reuse of materials and products (Fleischmann et al., 1997). Some authors also include remanufacturing (Kim et al., 2006) or refurbishing (Ravi et al., 2005) as integral parts. The relevance of profitability in RL becomes clear as it deals with returns management (i.e. returning bought products to the producer due to damages). Returns management often highly correlates with customer retention (Daugherty et al., 2002). To keep a stable customer base, it is essential for companies to implement a good RL strategy – not only for environmental goodwill. Especially for online retailers the topic becomes a major driver of firm success. Furthermore, RL includes the collection after the useful life of goods (ibid.). The measurability and indicators of the concept have led to various studies as the literature review of Carter and Ellram (1998) reveals. A RL process also describes the management and sale of returned products. Different from usual logistics research that investigates how to bring goods to the customers, RL changes the direction so that the product moves backward through the supply chain (Rogers & Tibben-Lembke, 2001). Defective products need to be taken back for repair and products at the end of their life cycle must be taken back for adequate disposal or recycling.

The study of Rubio, Chamorro and Miranda (2008) summarizes the characteristics of the research on RL from 1995 to 2005. The authors state that the concept has different definitions but conclude that the proposed definition of REVLOG at the beginning of this section can be considered the most complete.

2.2.5 Blue economy

Pauli (2010) developed this relatively young concept that is considered to be a vital source of inspiration for the CE according to the website of the Ellen MacArthur Foundation (2016). It is called

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blue economy referring to the colour of the ocean and sky, representing the largest components of the planet (Pauli, 2011). It is considered a value adding school of thought because the basic principles of the blue economy propose that the local environment, with its specific ecological features, is the basis for sustainable solutions. In total, the blue economy is defined by the following 6 principles (Blue economy, 2016):

1. it must be local so that companies use what they have close to them.
2. it should be efficient: Companies should “substitute something with nothing” (ibid., p. 1).
3. with a systemic approach the surrounding nature is mimicked.
4. the blue economy aims at profitable solutions through the optimisation and generation of “multiple cash flows” (ibid., p. 1).
5. it should satisfy “all basic needs” (ibid., p. 1) and
6. it calls for an innovative culture to create change.

Mechanisms as found in nature should be used in order to have an abundance of resources. For example, gravity is understood as the most important source of energy in the blue economy (Lieder & Rashid, 2016; Pauli, 2010). The hands-on focus through its practical ideas in the report to the Club of Rome, “10 years, 100 innovations, 100 million new jobs,” provides case studies for the further implementation (Pauli, 2010). The blue economy aims at protecting the global ecosystem while creating new job opportunities at the same time. It thus pursues a holistic approach, also addressing societal issues.

2.2.6 Regenerative design

Regenerative design is an approach based on systems theory that helps during the design stage of products and services. The word “regenerative” stands for the fact that energy and materials used for the design of products can be renewed and revitalized (Cole, 2012). This approach also relies on a closed loop input-output model (ibid.). Regenerative design is often achieved through biomimicry (Lieder et al., 2016). All material or waste should be reintroduced into the system or metamorphosed into new valuable resources at the end of the product’s life. This is how regenerative design aims at

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becoming completely waste-free. In addition, ecosystems services are considered as a template to design consumption so that services are bought instead of goods. The concept was developed by the architect Lyle (1996) who aimed at creating a framework for a community that can function with the locally available renewable resources without destroying them, while reducing unnecessary transportation efforts. Rodale (1983) worked on regenerative agriculture and has been an inspiring starting point for the research field of regenerative design to be spread out to other sectors of the economy. C2C surpassed the concept of regenerative design in terms of research since C2C seems to cover more aspects and therefore attracts the research interests of more scholars.

2.2.7 Performance economy

Stahel has developed the concept of the performance economy which is rooted in his works about the "functional service economy" (Stahel, 1994). It represents a utilization-focused service economy through resource efficiency and product-life extension. This approach highlights the environmental benefits when selling services instead of products, thereby also creating new job opportunities. Mont (2002) clarifies the meaning of a product-service economy: This kind of economy relies on product-service systems in order to decrease environmental damage through related production and consumption.

The performance economy aims at the maximum use value for the maximum amount of time. This way, the material input and energy used for a service shall be minimized. The performance economy thus wants to enhance sustainability through a more dematerialized system. Mont (2002) further highlights that companies must change their processes and organizational structures to implement the necessary product-service systems and that consumers must be willing to accept a service instead of owning the product. To summarize, the performance economy as a whole has primarily three goals: creating new jobs, increasing wealth and decreasing resource consumption (Product Life, 2016).

2.2.8 Natural capitalism

"Natural capital" is the world's natural assets such as air, water, soil and other organisms (Costanza & Daly, 1992). Through an economy based on the principles of natural capitalism, some scholars want to

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trigger the "next industrial revolution" (Hawken et al., 2013). In their model, the interests of the environment and businesses are not mutually exclusive, but have many overlaps. Natural capitalism has the following four principles (ibid.):

1. the productivity of natural capital must be increased. By adapting the design of products and using new technologies in production processes, natural capitalism aims at extending the usable life of resources. This shall allow to save costs and offer investment opportunities in new technologies.
2. biologically inspired production models should be implemented to reduce or eliminate waste through closed-loop production systems. Output should either return as a nutrient into the ecosystem or should be used as an input in another production process.
3. a "service-and-flow" (Hawkens et al., 2013, p. 134) business model should be encouraged as a promising alternative to the sale-of-goods model, offering value to customers while at the same time increasing resource productivity (Maxwell et al., 2006).
4. the cost savings from the prior principles allow businesses to reinvest into natural capital which will lead to a higher ratio of regeneration in natural resources. The methods for measurement are flexible and find inspiration in various indicators (Birkin, 2001).

2.2.9 Biomimicry

Biomimicry can be understood as imitating or being inspired by nature's superior designs to develop environmentally sustainable innovations (Reap, Baumeister, & Bras, 2005). Instead of re-inventing the wheel, biomimicry suggests that many of our problems have already been solved by nature. Thus, it aims at a better understanding of these mechanisms in order to copy them. Benyus (1997) states that the goal of biomimicry is to create products and processes functioning like natural components of the ecosystem without creating negative impacts to the environment. Biomimicry must not be confused with bionics (Dickinson, 1999). The latter is a more technical approach applying biological methods of natural systems to the innovation process of new technology. Biomimicry rather looks for systemic solutions and focuses on their sustainability (Passino, 2005). Consequently, a bionics approach would

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suggest a Velcro fastener - a product that was copied or inspired by nature - to be made out of plastics, while biomimicry would propose more nature-like materials, as plastic cannot be disposed without external effects on the environment (Mathews, 2011). Closed loop supply chains are also relevant for this concept as avoiding waste is a feature of nature. This fact makes it quite similar to the idea of the CE. The approach does not include specific measurement tools as it is rather related to new business models.

3 Comparison of concepts

3.1 Characteristics for comparison

Differentiating aspects of the concepts above have been derived into characteristics that are now used as a basis for comparison. Six broader categories comprising 24 detailed characteristics have been chosen for comparison. The categories one to five were deduced from the prior analysis of concepts, while category six was additionally included due to its inherent relevance to the concepts. It includes a primary focus on the product life cycle stages inspired by life cycle assessment (LCA) (Heiskanen, 2002) and the value chain activities from Porter's value chain framework (Porter & Advantage, 1985). The characteristics are explained below before the results are presented in Table 1.

The first two categories try to identify the main motivation and the position towards waste management of the concepts:

1. Motivation(s):

- *Focus on environment:* As some concepts are primarily motivated by more efficient production processes, they were examined to determine if they are still further motivated by environmental objectives.
- *Focus on profitability:* Some concepts promote the idea of closed loops to increase efficiency and profitability. Collecting old materials and reintroducing them into the production cycle can be financially beneficial.
- *Focus on social aspects:* This characteristic describes the social considerations of a concept,

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such as the creation of new jobs, socially responsible products, resource preservation, and increased well-being.

2. Proposition for waste management

- *Efficiency and waste reduction*: A central aspect of circularity is to reintroduce waste into the production loop by making it an input resource. Only concepts comprising this idea were analyzed. While some concepts achieve this objective with simply an efficient use of resources, others go a step further as seen in the next characteristic.
- *Zero waste:* This criterion tests if a concept aims at the full re-integration of waste into the product cycle as well as zero harmful impacts on the environment; e.g. by only using renewable energy sources and not emitting any toxic substances, even if used to recover materials in recycling processes.
- *Distinction between technological and biological substances*: For the ultimate goal of a CE it may be important to decide if all products should only be made out of “biological nutrients”, i.e. natural materials that potentially can re-enter the natural cycle without detrimental effects; or if man-made “technical ingredients” should be an option. Only some concepts explicitly distinguish between the two.

The third category examines the support and practical implications the concepts offer. While some are mainly formulating objectives or ideals, others want to give explicit advice on how to transform a business or society to a CE, or how to measure the success.

3. Guidelines and tools

- *Business model perspective*: A concept has this characteristic if it includes ideas for circularity within business models. This characteristic contrasts the characteristic “focus on profitability”.
- *Focus on operations*: A concept that focuses on operations is often a very detailed tool that mathematically measures how operations can be optimised. It intends to increase efficiency throughout its ongoing processes.

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- *Measurability:* Measurability refers to the question whether a concept includes information about how its implementation can be measured. Such concepts identify their own indicators, or adopt indicators, such as from LCA.
- *Governance*: Some concepts highlight and argue the importance of governmental support, e.g. incentivizing regulations

The last four categories deal with the economic characteristics of the concepts. We particularly want to distinguish the sectoral coverage, the economic perspective taken, and the activities included in the concept considerations. Categories four and five are derived from the preceding analysis of concepts. Category six further sharpens the comparison between the concepts with regard to their suggestions for circularity in product life cycle activities. For this purpose, Porter's value chain activities (Krykavskyy & Patora-Wysocka, 2015; Porter et al., 1985) and product LCA stages (Heiskanen, 2002) are utilized. LCA, on the other hand, is a standardized tool that allows the identification of environmental impacts of a product throughout its consecutive life stages, such as raw material sourcing, production, distribution, use & end of life (Heiskanen, 2002). In our analysis, distinct life cycle stage activities are identified as characteristics to be examined and are supported by additional value chain activities; where Porter's *sales and marketing*, and *aftersales services* are combined into a single *customer management* characteristic. Category six thus checks which stage activities are addressed in the different concepts.

4. Sectors Covered

- *Primary Sector:* concepts with this characteristic are applicable for industries dealing with natural resources: e.g. agriculture, mining, raw material suppliers
- *Secondary Sector:* Concepts with this characteristic are applicable for industrial manufacturing and assembly activities
- *Tertiary Sector:* Concepts including service based solutions-- selling intangible services or products as services, and reducing ownership, e.g. the sharing economy (Allen 2015).

5. Economic Scope

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- *Macro-economic perspective:* Does the concept consider the economy as a whole?
- *Meso-economic perspective*: Does the concept consider specific industries or sectors?
- *Micro-company perspective*: Does the concept consider the company level and its supply chain?
- *Micro-product perspective*: Does the concept explicitly consider the product level?

6. **Activities During Life Cycle Stages: circular considerations in the design of*:***

   - *Product Development*: what product is selected and how it is designed for the other stages of life
   - *Material sourcing:* Origin of production inputs, i.e. primary & secondary resources
   - *Production Processes:* how the production and assembly lines are configured and operated
   - *Transportation:* logistics and packaging required during any stage
   - *Use:* energy inputs, maintenance, and durability factors *End of Life:* material processing - recycle, upcycle, remanufacture
   - *Customer Management*: Sales and marketing, after sales services--including, repairs, refurbishment, and customer ownership transfers (reuse)

3.2 Results

The results of the literature review and concept analysis are aggregated in Table 1. This presents an overview of the current field of research by comparing and classifying the previously analysed concepts in relation to the characteristic based categories. It is important to note that during the analysis, the concepts' specific characteristics were only verified when the terms were explicitly used in the literature, to avoid misrepresentation or assumptions. Table 1 illustrates the overlaps among these related concepts and their positioning in relation to the CE as it has been described throughout literature, while verifying that no two concepts are identical. It further depicts the overall complexity and scope of each concept, progressing from the broadest scope on the left to the narrowest scope on the right. This was calculated by the volume of characteristics that were specifically addressed by each concept, providing a simple indicator to estimate their complexity across the group.

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The CE has the most characteristics in common with C2C, with the classification of material flows into technical components and biological nutrients being only included in these two concepts. However, C2C is limited to the micro and meso levels, while the CE focuses on macro and microeconomic perspectives, e.g. as can be seen with the specific macro and micro level performance indicators (Geng et al., 2012). In comparison to other concepts, CE, C2C, and regenerative design take a more fundamental stance with regard to waste: their goal is not only its reduction, but its full elimination. IE also has strong similarities with CE as it aims to shift the industrial part of the economy to closed cycles of energy and materials, with less waste. It is primarily the broader scope beyond industrial systems that makes CE richer in its content. Regenerative design as a concept is comparable with C2C because of its product design based approach. Regenerative design is also comparable with the performance economy or natural capitalism in its service based solutions. They similarly highlight the importance of selling services instead of goods. RL and CSC are similar in the respect that they take a detailed company or products based perspective (micro-level) and are motivated to increase the profitability of a company's supply chains.

The particular measurability characteristic has further implications. All concepts, except for biomimicry and regenerative design, attempt to prescribe various indicators to measure performance in their conceptualization. The applied indicators of each concept depend on their specific focus and therefore include only a limited scope of measurements that alone cannot capture the performance of the CE. For example, C2C has developed its own broad range of indicators, capturing circularity as well as social aspects. CSC and RL are quite similar in terms of their indicators, as they all mainly focus on profitability metrics. However, they also include broader indicators such as the recycling rate. The blue economy also has primarily profitability orientated indicators, complemented with a few environmental and social indicators. The performance economy proposes measurement ideas for the service systems, although does not focus on circularity as such. Natural capitalism incorporates natural capital accounting indicators without making reference to particularly circular indicators. Considering these various indicators may be useful for developing a comprehensive set of proxy

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indicators for the CE, although maintaining a grasp on the relevance and distinct scope of each concept will be critical.

4 Conclusion

This research as a deliverable of the *R2π* project provides a contemporary literature review of the CE and the closely associated concepts. It clarifies a common conceptual ground and understanding for advancing the project goals. Achieving a refined differentiation between the concepts provides a toolkit for their use and understanding to support the implementation of the complex CE concept. Additionally, the concept analysis has provided a review of the current definition of CE from literature, and provides a foundation to identify potential improvements for the next deliverable. The research reveals that the adjacent CE concepts are rather interconnected, but have unique focuses, characteristics, and goals– many of which may play important roles in realizing a CE. Nevertheless, it is critical to understand the differences when formulating the research structure and framing methodologies to progress the knowledge and adoption of the CE. This research will be succeeded by the next deliverable of the project, addressing the formulation of the working definitions and research ontology for *R2π.*

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Table 1: Comparison of CE Concepts from Literature Review

Categories	Characteristics	Concepts: Circular economy	Cradle to cradle	Closed supply chains	Regnerative design	Blue economy	Industrial ecology	Reverse logistics	Perfor-mance economy	Natural capitalism	Bio-mimicry
Motivation(s)	Focus on environment	●	●	●	●	●	●	●	●	●	●
	Focus on profitability			●				●			●
	Including social aspects	●	●		●	●			●	●	
Proposition for waste management	Efficiency and waste reduction	●	●	●	●	●	●	●	●	●	●
	Zero waste	●	●		●						
	Technological/ biological substances	●	●								
Guidelines and tools	Business model perspective	●	●			●				●	
	Focus on operations		●	●	●		●	●			
	Measurability	●	●	●		●	●	●	●	●	
	Governance	●		●			●				
Economic Sectors covered	Primary Sector	●	●		●	●	●			●	
	Secondary Sector	●	●	●	●	●	●	●	●	●	●
	Tertiary Sector	●	●		●	●			●	●	
Economic scope	Macro-economic perspective	●				●			●	●	
	Meso-economic perspective		●	●			●				
	Micro: company level	●	●	●	●		●	●			
	Micro: product level	●	●		●			●			●
Activities During Life Cycle Stages: *Circular Design of...*	Product Development	●	●	●	●	●			●	●	●
	Raw material sourcing	●	●	●							●
	Production processes	●	●	●		●	●	●			●
	Use	●	●						●		●
	Customer Management							●	●		
	End of life/ disposal	●	●	●	●	●	●	●	●	●	●
	Transportation	●	●	●	●	●	●				

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5 References

Literature exploration on the concept of a "Circular Economy" and related concepts, dealing with circularity in economics

- Circular Economy
- Cradle to cradle
- Industrial ecology
- Closed (loop) supply chains
- Reverse logistics
- Blue economy
- Performance economy
- Natural capitalism
- Biomimicry
- Regenerative design
- + Life Cycle Assessment, Circular Economy and sources on the background of the concept

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