# Leveraging innovation for the transformation to a Circular Economy – The case of Germany's construction and manufacturing industries

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# Summary

In recent years, the Circular Economy (CE) has been increasingly presented as an alternative to the world's current linear economic system by scholars and governments alike (Blomsma & Brennan, 2017; Geissdoerfer et al., 2017). The concept of the Circular Economy combines economic, social, and environmental objectives to address multidimensional challenges, such as resource scarcity, environmental pollution, climate change, and high inflation rates, increasingly faced by society and businesses across the world (Kirchherr et al., 2017; Lieder & Rashid, 2016). Particularly resource-intensive industries such as the construction and manufacturing industries have come under pressure from rising resource prices (Ellen MacArthur Foundation, 2015a; ifo Institute, 2022), government regulation (Directive 2008/98/EC, 2008; Kreislaufwirtschaftsgesetz (KrWG), 2012), and customer demands to implement the Circular Economy.

Despite its promising aspirations, CE implementation rates remain low (K. T. Adams et al., 2017; Eurostat, 2024; Kirchherr et al., 2017). In light of a variety of implementation barriers (Kirchherr et al., 2018; Tura et al., 2019), there is a need for research to examine how the gap between the high aspirations and the low implementation rates of the CE can be addressed from both an academic and practice-oriented perspective. A crucial role in this process is ascribed to innovation, and scholars have been calling for research "to understand how, and by which means, innovation is able to facilitate the emergence of a CE" (de Jesus & Mendonça, 2018, p. 76).

To address the question of how companies in the German construction and manufacturing industries can leverage innovation to accelerate the transformation to a Circular Economy, this dissertation applies a hybrid research approach consisting of two studies. A first, survey-based, quantitative study examines the impact of innovation capabilities and business analytics capabilities on CE implementation, as well as the impact of CE implementation on firm performance. The results confirm a significant positive effect of both innovation capabilities and business analytics capabilities for CE implementation. Furthermore, they provide crucial evidence for the positive impact of CE implementation on firm performance.

Building on these findings, a subsequent qualitative, interview-based study explores the role of innovation in CE implementation in more detail. The interviews were conducted among CE frontrunners in the construction and manufacturing industries in Germany and yield three main

findings. Firstly, the study reveals distinct types of circular innovations pursued by CE frontrunners of both industries, each with different benefits and costs. Secondly, it sheds light on the decision-making process for the implementation of circular innovations. When deciding the implementation of circular innovations, CE frontrunners consider not only a monetary dimension but also non-monetary business value, as well as the social and environmental value of circular innovations. This dissertation combines these insights from the decision-making process of CE frontrunners and develops a framework for companies to assess circular innovations.

Thirdly, and potentially most importantly regarding implications to both theory and practice, this dissertation expands an established model of innovation capabilities (Lawson & Samson, 2001) and identifies 38 concrete capabilities across nine dimensions, which have been essential for the success of circular innovations among CE frontrunners. In the context of the findings of the quantitative study that innovation capabilities can have a positive effect on CE implementation in companies, these findings offer a starting point to support companies beginning their transition to a circular business model. At the same time, they extend the CE and innovation literature by demonstrating the link between innovation and CE implementation and presenting concrete implementation-oriented insights among CE frontrunners.

## Preface

This dissertation is based on two independently collected data sets. One data set stems from a survey conducted in January and February 2022, and the other from interviews conducted in spring 2023. Funding for the survey data collection in 2022 was provided by the Finnish Academy of Science research and innovation program (grant agreement No. 337722). To share initial findings from the data before publishing this dissertation and, therefore contribute to the emerging research field of the Circular Economy, I have published partial findings from the data in two previous publications: One conference paper titled *‘The Influence of Circular Economy Implementation on Competitiveness in Manufacturing Companies’* (Saari et al., 2022) and one article in the Journal of Cleaner Production titled *‘Capabilities for circular economy innovation: Factors leading to product/service innovations in the construction and manufacturing industries’* (Saari et al., 2023). The same data set is used as a basis for the quantitative study of this dissertation, therefore there are certain limited overlaps in the analyzed data and considered constructs. However, this dissertation’s research question, data model, and scope of analysis of the data set differ distinctly. The qualitative study of this dissertation was entirely independently developed from previous publications.

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## List of Abbreviations

| | |
|---|---|
| AVE | Average variance extracted |
| BA | Business analytics |
| BAC | Business analytics capabilities |
| BDAC | Big data analytics capabilities |
| BIM | Business information modeling |
| C&D | Construction & demolition |
| C2C | Cradle-to-Cradle |
| CBM | Circular business model |
| CE | Circular Economy |
| CEI | Circular Economy implementation |
| $CO_2$ | Carbon dioxide |
| COI | Circular oriented innovation |
| CRM | Critical raw materials |
| DfR | Design for recycling |
| DfX | Design for reuse, refurbishment, and recycling |
| DPP | Digital product pass |
| DT | Digital technologies |
| EEA | European Environment Agency |
| EI | Eco-Innovation |
| EMF | Ellen MacArthur Foundation |
| EOL | End-of-life |
| ESPR | Ecodesign for Sustainable Products Regulation |
| EU | European Union |
| FMCG | Fast moving consumer goods |
| GHG | Greenhouse gas |
| HOC | Higher-order construct |
| HTMT | Heterotrait-monotrait ratio |
| ICA | Innovation capabilities |
| LM | Linear regression model |
| LOC | Lower-order construct |

| | |
|---|---|
| MACC | Marginal Abatement Cost Curve |
| MNC | Multi-national corporation |
| MSW | Municipal solid waste |
| OEM | Original equipment manufacturer |
| PER | Firm performance |
| PLS | Partial least squares |
| PLS-SEM | Partial least squares structural equation modeling |
| PoC | Proof of concept |
| RMSE | Root mean square error |
| ROI | Returns on investment |
| SDGs | Sustainable Development Goals |
| SEM | Structural equation modeling |
| SME | Small and medium-sized enterprise |
| SOI | Sustainability oriented innovation |
| TBL | Triple bottom line |
| USP | Unique selling proposition |
| VIF | Variance inflation factor |

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# 1. Introduction

## 1.1. Research relevance

Our planet's resources are limited and cannot sustain current rates of economic development indefinitely. The environment in which we live is unable to absorb the ever-increasing amount of waste that we produce without suffering irreversible damage.

These statements remain as true today as they were when first made over fifty years ago (Boulding, 1966; Meadows et al., 1972). What has changed since then is the urgency with which we, as humans, need to address these issues. As climate change and resource scarcity continue to progress, recent global crises such as the COVID-19 pandemic and the Russian war against Ukraine have further highlighted the fragility of global supply chains and the finite nature of our planet's resources.

Under the promise of enabling sustainable economic growth within the limits of planetary resources and thus being able to address these issues, the concept of the Circular Economy (CE) has increasingly come into focus, especially in recent years. Proposed as an alternative to the current linear economic system, the Circular Economy fundamentally challenges the take-make-use-waste approach that has defined economic activity across the globe for centuries (Geissdoerfer et al., 2017). Instead, the CE proposes a model that retains resources in closed loops and eliminates waste (Lieder & Rashid, 2016). Originally introduced as a concept in the 1990s (Pearce & Turner, 1990), the CE fundamentally challenges how we need to think about goods and services and sees existing products as a source of nutrients and new materials instead of a source of waste (McDonough & Braungart, 2002). According to these principles, the CE attempts to reconcile three objectives: "simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations" (Kirchherr et al., 2017, p. 229).

Widely adopted by governments, laws have been passed around the world in recent years to implement the Circular Economy across industries (Directive 2008/98/EC, 2008; Kreislaufwirtschaftsgesetz (KrWG), 2012). At the same time, consumer preferences have shown signs of a shift towards both sustainable and circular products specifically (Boyer et al., 2021; White et al., 2019).

Firms in resource and waste-intensive industries, such as construction and manufacturing, are facing mounting pressure from various sources. This includes new legislation and regulations, rising prices for finite raw materials, supply chain insecurities, and evolving customer preferences. To address these challenges, they must introduce circular products and business models. Among all firms across the value chain, producers face one of the largest burdens of bringing the concept of the Circular Economy to life, as design is at the core of all CE efforts and is key to creating the conditions for materials to circulate continuously in closed loops and for waste to be eliminated (Ellen MacArthur Foundation, 2013; McDonough & Braungart, 2002).

Pull factors also drive the transition to a Circular Economy, as it can offer significant business opportunities. Early estimates have proclaimed an annual total benefit from adopting CE principles of €1.8 trillion by 2030 for Europe alone (McKinsey & Company, 2015). At the level of individual companies, the CE offers new profit opportunities by reducing material costs, creating additional revenue streams, such as from new business services, and enhancing customer loyalty (Ellen MacArthur Foundation, 2015b). Given the increasing scarcity of resources and the pressure on governments and businesses alike to respond to climate change, not only does the transition to a Circular Economy seem increasingly inevitable, but such a transition can also offer clear opportunities and benefits for individual businesses.

In contrast to this, CE implementation (CEI) in practice remains at a comparatively low level (K. T. Adams et al., 2017; Kirchherr et al., 2018). The Circularity Gap Report, which is published annually by the Platform for Accelerating the Circular Economy (PACE) and calculates circularity levels as cycled materials divided by total material use of society, argues that in 2023, the world had only achieved a circularity level of 7.2%. Even worse, however, this represents a 21% drop from the already low level of 9.1% in 2018 (Circle Economy, 2024). The figures for Europe promise only slightly better prospects, with the circular material use rate (share of material recovered and cycled back into the economy of overall material use) for 2022 reported at an average of 11.5% across the European Union and 13.0% for Germany (Eurostat, 2024).

In Germany specifically, total waste generation reached an all-time high in 2018, culminating at 417 million tons[1]. Although the slightly declining figures for 2019-2021 (412 million tons in 2021) could be an initial indication of a trend reversal, the figures should be treated with caution in light of the COVID-19 pandemic and the associated economic downturn (Statistisches Bundesamt, 2023).

Over the last years, a constantly growing research interest has attempted to shed light on the CE, its potential, and the reasons for the slow development of implementation rates so far (Geissdoerfer et al., 2017; Lieder & Rashid, 2016). It is without alternative to increase these implementation rates to protect the planet's finite resources and mitigate the threats of ever-increasing waste streams and advancing climate change. This dissertation aims to contribute to addressing these urgent challenges and promote the implementation of the Circular Economy.

### 1.2. Research objectives and research questions

Prior research has identified governments and companies as the two actors at the center of the CE concept (Geissdoerfer et al., 2017). They are the ones whose main responsibility it will be to advance CE implementation and to increase current circularity levels. Governments have slowly begun to respond to the challenge over the last years. They have introduced numerous laws and regulations, both in Europe and Germany, each slightly more ambitious than the previous (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2020; Directive 2008/98/EC, 2008; Kreislaufwirtschaftsgesetz (KrWG), 2012).

From a CE perspective, these laws still fall short of those that would be needed to establish a truly circular economic system under the principles of C2C. Nonetheless, they have been important steps in the right direction. At the same time, research has been very clear in formulating additional recommendations for action for governments to make existing legislation and regulations even more effective or to introduce additional ones, where necessary (Circular Economy Initiative Deutschland (Ed.) et al., 2021; Hartley et al., 2020). Equipped with such a roadmap and with adequate resources, it is now about getting governments to

[1] Of which: 222 tons construction & demolition (C&D) waste, 52 tons household waste, 29 tons mining & quarrying waste, 59 tons secondary waste from waste treatment facilities, and 50 tons other waste (especially from production and manufacturing) (Statistisches Bundesamt, 2023)

implement the necessary legislation and regulations. In other words, it is mostly known what needs to be done. Now, it is about doing it in practice.

For companies, the second actor argued by Geissdoerfer et al. (2017) to be at the center of the CE, the roadmap to increasing circularity rates is not quite as clear. Early research on CE implementation on a firm level has uncovered a wide range of barriers, ranging from high up-front investment costs (Kirchherr et al., 2018; Tura et al., 2019), a lack of technology and technical skills (Geng & Doberstein, 2008; Kumar et al., 2019), to hesitant company cultures (Grafström & Aasma, 2021; Kumar et al., 2019), or lacking customer demands (Huang et al., 2018; Tura et al., 2019), to name just a few.

Although research also proposes enablers for the Circular Economy (K. T. Adams et al., 2017; Urbinati et al., 2021), these enablers mostly remain at a very high level and are rarely concrete and action-oriented from the perspective of companies looking to implement the CE. An exception to this have been efforts by non-academic promotors of the CE, notably the Ellen MacArthur Foundation, to showcase examples of lighthouse innovations from individual companies and combine them with concrete advice for the majority of companies that are still in the early stages of implementing circular products or business models (Ellen MacArthur Foundation, 2020a, 2020b). Prior research has, therefore, correctly identified a "deficit of implementation-oriented empirical research on a firm-level" (Drabe (née Geng) & Herstatt, 2016, p. 3) in academic literature. Only recently, research appears to have begun to address this gap systematically and has "moved from purely conceptual work into empirical studies and research into implementation tools" (Bjørnbet et al., 2021, p. 1).

This dissertation aspires to contribute to the next chapter of CE research, going beyond conceptual work and the identification of barriers and enablers toward an understanding of how companies can drive CE implementation in practice. As companies have to radically adapt products, processes, and even business models if the transition to the CE is to succeed (Prieto-Sandoval et al., 2018), a high degree of innovativeness will be required to bring about this radical change (Suchek et al., 2021).

Due to the novelty of the field, a recent literature review on innovation and the CE summarizes that "research into innovation remains fragmented with diverse and different dimensions investigated" (Suchek et al., 2021, p. 3687). However, early research has identified activities such as product innovation and product design innovation (Bocken et al., 2016), process innovation (de Jesus et al., 2021), organizational innovation (Suchek et al., 2021), and maybe most importantly, innovation in the business model itself (Pieroni et al., 2019) as necessary for firms on the path towards a CE.

This dissertation aims to expand this stream of CE literature, responding to calls "to understand how, and by which means, innovation is able to facilitate the emergence of a CE" (de Jesus & Mendonça, 2018, p. 76). Therefore, the primary goal of this dissertation is, to examine *the role of innovation for the implementation of a Circular Economy.* The focus is on two particularly resource-intensive industries, the construction and manufacturing industries, which are characterized not only by their high demand for materials but also because they are two of the three industries responsible for the largest share of waste in Germany (Statistisches Bundesamt, 2023).

The research objective is approached in two ways. Firstly, a quantitative study is conducted to determine how innovation capabilities (Lawson & Samson, 2001) and business analytics capabilities (Akter et al., 2016; Kristoffersen et al., 2020) can assist firms with CE implementation (CEI). Furthermore, the quantitative study examines how CEI contributes to firm performance, thereby assessing its effect on "the ultimate dependent variable of interest for researchers concerned with just about any area of management" (Richard et al., 2009, p. 719). Business analytics capabilities are assessed alongside innovation capabilities, as research on CE has increasingly highlighted the positive impact that digital technologies, business analytics, and associated capabilities can have on CE implementation (Antikainen et al., 2018; Kristoffersen et al., 2021a). However, the main focus of this dissertation remains on the role of innovation and innovation capabilities in CE implementation.

The quantitative study addresses the first research question:

> *RQ 1: How do innovation- and business analytics capabilities assist firms in the construction and manufacturing industries with Circular Economy implementation and how does Circular Economy implementation impact firm performance?*

Based on the results of the quantitative study, a second, qualitative study was conducted among CE frontrunners in the construction and manufacturing industries in Germany. This study aims to provide additional in-depth insights into the role of innovation for CEI and the development of innovation capabilities at the firm level, thereby contributing to filling the gap identified in the literature (de Jesus & Mendonça, 2018; Drabe (née Geng) & Herstatt, 2016).

In this context, the qualitative study addresses the second research question:

> *RQ 2: How can firms in the construction and manufacturing industries leverage innovation for the implementation of the Circular Economy in practice?*

Particularly with the answer to the second research question, this dissertation attempts to provide concrete and applicable managerial implications for firms trying to transition from a linear to a circular business model.

# 2. Theoretical background

## 2.1. The Circular Economy as a sustainable alternative to our current economic system

### 2.1.1. History of the Circular Economy

The foundations of the concept of the Circular Economy are not as new as one might think. Blomsma & Brennan (2017), who provide a historical overview of the development of the concept of the CE, identify the first developments in the 1960s, even though those were not yet referred to as a Circular Economy. They divide the development of the CE into three phases: a *'preamble'* from 1960 to 1985, an *'excitement period'* from 1985 to 2013, and a *'validity challenge period'* from 2013 to the present day (Blomsma & Brennan, 2017).

Recent literature often credits Boulding (1966) for laying the foundations of what we now know as a Circular Economy. He argued that the open economic model in place at that time, which he referred to as a *'Cowboy Economy'*, could not be sustainable in the long run. Instead, he proposed a new concept of a *'Spaceship Economy'*, "in which the earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution, and in which, therefore, man must find his place in cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy" (Boulding, 1966, pp. 7–8).

During this period, the *'The Limits to Growth'* report from the Club of Rome brought global attention to the issue of resource scarcity. The report pointed out that resources such as food, land, metals, and other natural resources will eventually run out, and at a faster rate, as the population continues to grow (Meadows et al., 1972). Addressing resource scarcity remains one of the key pillars of the CE concept today (Lieder & Rashid, 2016).

Interestingly, the terms *'closed'* and *'cyclical'*, which still remain at the center of the CE, were key parts of the concept already back in 1966 (Boulding, 1966). Murray et al. (2017) credit Stahel & Reday-Mulvey (1976) as the first authors to refer to this alternative economic system as a *'closed-loop economy'*. During this *'preamble'* period, waste was still perceived as harmful, and early industrial recycling efforts mainly focused on reducing negative end-of-life (EOL) effects (Blomsma & Brennan, 2017).

With the beginning of the *'excitement period',* the term Circular Economy, as we know it today, was introduced. In their pioneering work *'Economics of Natural Resources and the Environment'*, Pearce and Turner (1990) expanded on the work of Boulding (1966) and were the first to propose an economic model for the Circular Economy. Beginning with their work, the view on waste changed significantly. It began to shift from purely negative to seeing waste "as a resource and a source of value" (Blomsma & Brennan, 2017, p. 608). Pearce and Turner (1990) integrate 'recycling' into their economic model as a way to convert waste back to resources. Basing their model on the laws of thermodynamics, they argue for "three economic functions of the environment – as resource supplier, as waste assimilator, and as a direct source of utility" (Pearce & Turner, 1990, p. 41).

During the *'excitement period'*, the CE concept eventually started to become acknowledged on a larger scale outside of academia as well. "In Germany, in the early 1990's, the CE concept was introduced into environmental policy with the intent to address issues associated with raw material and natural resource use for sustained economic growth" (Winans et al., 2017, p. 826). The *'Law on the Avoidance, Treatment, and Disposal of Waste'* (Gesetz Zur Vermeidung, Verwertung Und Beseitigung von Abfällen, 1994) marks the beginning of legislative efforts in Germany to promote the implementation of a Circular Economy.

Other countries soon passed the first legislation of their own. In the year 2000, the *Basic Act for Establishing a Sound Material-Cycle Society* was passed in Japan (Basic Act for Establishing a Sound Material-Cycle Society, 2000). Similarly, in 2008, the People's Republic of China officially passed the *Circular Economy Promotion Law of the People's Republic of China* (Circular Economy Promotion Law of the People's Republic of China, 2008). Other governments, notably in Europe and the US, followed suit and also passed laws of their own in the area of sustainable material or waste management in the late 1980s, 1990s, and early 2000s (Blomsma & Brennan, 2017).

More recently, the 2008 *'Directive on Waste'* (Directive 2008/98/EC, 2008) by the European Commission and the *'Circular Economy Law (KrWG)'* (Kreislaufwirtschaftsgesetz (KrWG), 2012), derived from said directive, represent particularly noteworthy efforts to promote the CE through legislation and regulation in Germany and in the EU. Since then, the law has been adapted and tightened by the German government on multiple occasions (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2020).

After the year 2000, the concept of the CE also began to gain more and more traction as a research field. A literature review by Lieder and Rashid (2016) shows that very few papers on the CE were published before the year 2007, with a substantial increase in publications only occurring after 2008. Most of these early publications on the CE are, in fact, focused on China and, only as of 2013 has the share of geographically independent publications risen (Lieder & Rashid, 2016). These findings are confirmed by similar literature reviews (de Jesus et al., 2021; Geissdoerfer et al., 2017). However, in comparison to the overall topic of sustainability, the number of publications on CE remains relatively small despite an increase in recent years (Geissdoerfer et al., 2017).

During the last years, also more and more non-governmental institutions such as the World Economic Forum (WEF) or the Ellen MacArthur Foundation (EMF) emerged as important promotors, as well as thought-leaders on the CE. Also, consultancies such as McKinsey & Company started focusing more and more on the CE and actively began to promote and develop the concept (Ellen MacArthur Foundation, 2013). At the same time, many private sector corporations are actively beginning to pursue CE ambitions. One example of this is the 'Global Commitment Initiative', which has been established by the EMF together with the UN Environment Program to establish a CE for plastics. To date, it has been signed by over 500 signatories, which account for 20% of all plastic packaging produced worldwide (Ellen MacArthur Foundation, 2020b). Other examples of particularly innovative circular initiatives of individual companies have been compiled by actors such as the EMF (Ellen MacArthur Foundation, 2020a, 2020b). These examples illustrate a recent increase in interest in the CE at the company level, similar to the increase in interest in academic literature.

### 2.1.2. Main principles for the Circular Economy

As the concept of the CE developed over the last 30 years, so did the view of what a CE should include and what it should not include. When first introduced in the 1990s, 'recycling' and a sustainable 'mining' of renewable resources, respecting their respective growth rates, were at the center of the model for a CE (Pearce & Turner, 1990). More recently, this view has broadened, and researchers, as well as governments proposing the CE, have begun to base their view of the CE on the 3Rs principle (reduce, reuse, recycle) (Ghisellini et al., 2016). Since the first introduction of the 'Rs', they have repeatedly been expanded and modified, with recent research proposing as many as 10R strategies (Potting et al., 2017). Each of these strategies refers to a concrete action aimed at reducing waste and dependency on virgin raw materials.

Today, the different CE strategies along the 10Rs can also be found in the recently passed legislation at both the EU and national level in Germany. Some laws have aimed at increasing the utilization of recycled materials in new products, for example, requiring the use of recycled lead, lithium, and cobalt in new electric vehicle (EV) batteries (European Parliament, 2023), hence promoting the ‘recycle’ strategy. To promote ‘reuse‘, a law has been introduced on the national level in Germany requiring shop owners to offer a reusable alternative for disposable plastic food packaging and disposable drink cups (Verpackungsgesetz (VerpackG), 2023). Other legislation, such as a proposal for an EU directive to promote the repair of goods, thus addressing the ‘repair’ strategy, is under discussion at the EU level at the time of writing this dissertation (European Commission, 2023c).

The theoretical origins of both the individual ‘R’ principles and CE as a whole can be traced to broader sustainability literature. There are overlaps between the two streams of literature, but there are also significant differences. It is important to note that the concept of the CE should not be equated with sustainability, despite the terms often being used interchangeably in both research and practice. Most importantly, the objectives of the CE are narrower and more concrete, as it is “aiming at a closed loop, eliminating all resource inputs and waste and emission leakages of the system” (Geissdoerfer et al., 2017, p. 764). The sustainability goals, on the other hand, address a broader spectrum of issues. This is also illustrated by the United Nation’s 17 Sustainable Development Goals (SDGs), arguably the most widespread and accepted summary of these goals (UN General Assembly, 2015). Another striking difference between the two concepts concerns agency, which in the case of sustainability, rests on the shoulders of all kinds of actors, whereas CE requires action primarily from governments and businesses (Geissdoerfer et al., 2017).

As similarities between the two concepts remain, the principles of the CE and the underlying strategies incorporate elements from various schools of thought on sustainability, as Bocken et al. (2016) point out. Firstly, there are those strategies and principles that are primarily concerned with *narrowing resource loops*. The ‘reduce’ principle, for example, primarily promotes the concept of eco-efficiency, which, in essence, suggests doing the same with less, i.e., producing the same product with fewer resources (Ehrenfeld, 2005). It hence proposes a reduction of waste and emissions but ultimately does not aim to abolish waste creation altogether.

Secondly, there are those strategies that aim to extend the lifespan of a product and, therefore, postpone the point at which it becomes waste, i.e., *slowing resource flows* (Bocken et al., 2016). Examples of circular strategies in this category include 'reuse', 'repair', 'refurbish', or 'remanufacture' (Potting et al., 2017). Nevertheless, none of these strategies, at least not by itself, can close resource loops and eliminate the creation of new waste.

Last but not least, some strategies aim to completely *close resource loops*. They incorporate elements from the Cradle to Cradle (C2C) school of thought, which sees any materials used in products not as waste but either as nutrients for the biosphere or as a source for new products in the technosphere (McDonough & Braungart, 2002). The circular strategy of 'recycling' falls into this category of closing resource loops, even though Bocken et al. (2016) correctly differentiate between primary, secondary, tertiary, and even quaternary recycling, where only primary recycling retains the equivalent properties of the material and hence follows C2C standards. Secondary, tertiary, and even quaternary recycling represents a form of downcycling, as materials lose their quality.

Ultimately, neither slowing nor narrowing resource loops for finite, non-renewable resources will be enough to ensure long-term survival on our planet, at least not if not combined with efforts to close resource loops altogether. This had already been recognized by Boulding (1966) and Pearce and Turner (1990).

To translate the theoretical debate around CE principles and strategies into a framework that can guide governments as well as companies in their actions to implement a CE, the Ellen MacArthur Foundation (2019) developed the *Circular Economy Systems Diagram* (Figure 1).

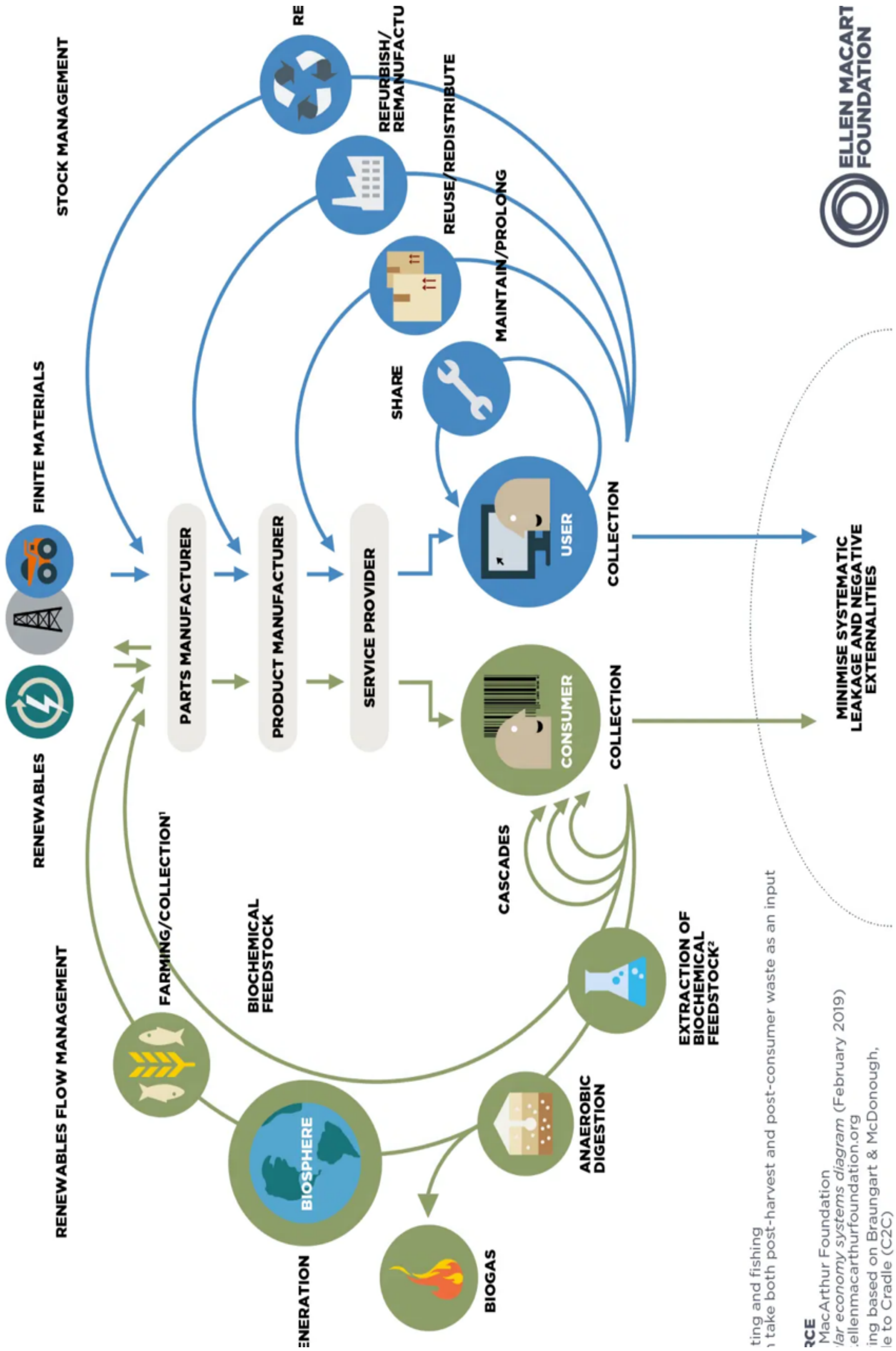


**Figure 1: Circular Economy Systems Diagram**[2]

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[2] Source: Ellen MacArthur Foundation (2019)

The diagram introduces two additional, essential aspects to the CE concept. Firstly, it acknowledges the need to differentiate between a biological cycle and a technical cycle, thus incorporating insights from the C2C concept. After use, materials in the biological cycle serve as nutrients for the biosphere, while those in the technical cycle are eventually recycled to serve as materials for new products, replacing virgin materials (McDonough & Braungart, 2002).

Secondly, by introducing the loops, especially in the technical cycle, the diagram proposes a hierarchy for the different CE strategies. This thinking links back to the waste hierarchy, initially proposed by the European Commission in 2008, to prioritize waste prevention legislation and waste management legislation to ensure the best environmental impact (Directive 2008/98/EC, 2008). The Ellen MacArthur Foundation (2019) argues that prioritization of the inner loops of ‘sharing’, ‘maintaining/prolonging’, and ‘reusing/redistributing’ results in economic benefits for producers as well as customers, primarily as the embedded value in the products is retained. Only as a last resort should products be recycled and their materials recovered (Ellen MacArthur Foundation, 2019).

### 2.1.3. Definition of the Circular Economy

As with most emerging and fast-developing research fields, not all authors who publish on the CE share the same understanding or definition of what a Circular Economy is. Kirchherr et al. (2017) observed that among a sample of 114 definitions of the CE, only four definitions were used more than once, with the most employed definition also only being used twelve times. Yet, finding and agreeing on a definition for the CE is crucial because “if subverted definitions start dominating, CE implementation will only result in incremental improvements at best, with the CE concept then not delivering on its promise of fundamental change” (Kirchherr et al., 2017, p. 229).

Two definitions have since then emerged as the most prominent ones for the CE. Firstly, a definition subsequently developed by Kirchherr et al. (2017) to unify all the different definitions in academic literature: “A circular economy describes an economic system that is based on business models which replace the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations*"* (Kirchherr et al., 2017, pp. 224–225). This definition has been accepted by many authors since. However, it puts significant focus on *'reducing'* and *'recycling',* and while these are commonly adopted and even encouraged practices, practice has shown that reduction is in many cases often wrongly understood as eco-efficiency, while recycling in its current form frequently leads to downcycling and a loss of materials in the long term.

A true Circular Economy, aiming to eliminate waste, should be based on the C2C design principle instead, effectively eliminating waste rather than only reducing it (McDonough & Braungart, 2002). Therefore, this dissertation has decided to adopt an older definition of the CE, which has been developed by the Ellen MacArthur Foundation (EMF), one of the most important thought-leaders for the CE. According to their definition, "a circular economy 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" (Ellen MacArthur Foundation, 2013, p. 7).

#### 2.1.4. Current state of Circular Economy implementation

Before going into detail about the state of CE implementation in the construction and manufacturing industry in section 2.2, this section will give a concise overview of the overall state of CE implementation, with a focus on Germany.

The *Status Report of the German Circular Economy 2024*, compiled by leading associations across the value chain, summarizes the importance of CE activities for the German economy. In 2024, more than 315,000 employees were employed across 10,000 companies, contributing to revenues of €105 billion and a gross value added of €33 billion (Prognos AG, 2024, p. 5). This represents an increase in revenues (+23%) as well as gross value added (+18%) in comparison to 2020 figures (Prognos AG, 2020).

However, many authors in the academic literature remark that despite significant scholarly attention, progress in terms of concrete CE implementation across the world has been limited (K. T. Adams et al., 2017; Kirchherr et al., 2018). Even Germany, which was one of the first countries to introduce recycling initiatives for certain materials rigorously, "still has a long way to go before achieving genuine circularity" (Circular Economy Initiative Deutschland (Ed.)

et al., 2021, p. 22). This is why the authors of the report on CE implementation in Germany argue that "at present, Germany's Circular Economy could therefore be more accurately described as 'recycling-based waste management'" (Circular Economy Initiative Deutschland (Ed.) et al., 2021, p. 24).

As already described in section 1.1, data from the Circularity Gap Report provides further evidence for these claims. The global circularity level of 7.2% in 2023 (cycled materials divided by total material use of society) marks the latest low of this statistic, following a continuous decrease of said figure since it was first reported in 2018 (Circle Economy, 2024). In the EU, circular material use rates (share of material recovered and cycled back into the economy of overall material use) have hovered around ~11.5% in the period between 2016 and 2022. Germany slightly exceeds the EU-27 average, reporting a rate of 13% in 2022, but trails far behind other countries such as the Netherlands (27.5% in 2022) or Belgium (22.2% in 2022) (Eurostat, 2024).

Of course, one must keep in mind that transitioning to an entirely new economic system requires decades of change and is a gradual and not an abrupt process. Nonetheless, given the urgency to address the pressing issues of climate change, resource depletion, and waste pollution, these assessments of the state of CE implementation are alarming. It is concerning that implementation rates remain so low even in developed countries. This also increases the pressure on governments and private actors alike to increase speed towards CE implementation, making it increasingly important for academic research to provide concrete support and recommendations.

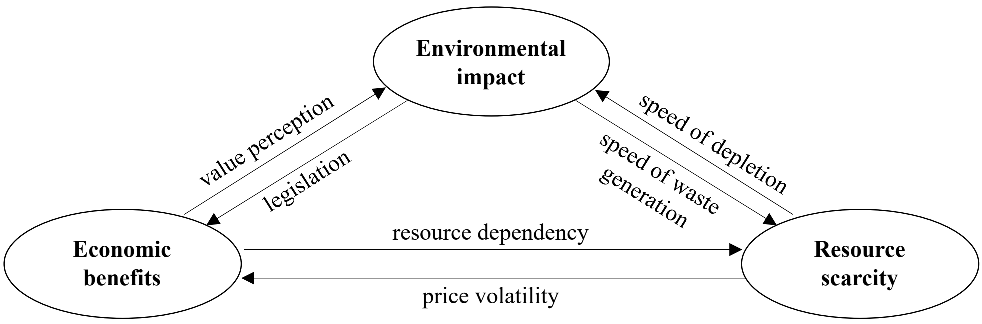
### 2.2. The construction and manufacturing industries in the context of the Circular Economy

As previously mentioned, this paper has decided to focus on two specific industries, namely the construction and manufacturing industries. They have been chosen as they are among the largest generators of waste (Eurostat, 2023) and, at the same time, received comparatively little scholarly attention to date (K. T. Adams et al., 2017; Bjørnbet et al., 2021). Especially for these two industries, previous research has called for the next steps to be taken beyond the identification of barriers and enablers and to "define what is required to put the enablers into practice and accelerate uptake of CE in the built environment" (Hart et al., 2019, p. 624). For the manufacturing industry, too, recent literature reviews "suggest a continued effort to build a solid base of empirical research on CE" (Bjørnbet et al., 2021, p. 12).

Going forward, the construction industry is defined according to the NACE Rev. 2, the *Statistical classification of economic activities in the European Community,* per section F, including activities in the sector of the construction of buildings (41), civil engineering (42), and specialized construction activities (43) (Eurostat, 2008). As for the manufacturing industry, this paper focuses on several sub-sectors of the manufacturing industry and not on the manufacturing industry as a whole. These subsectors, again classified according to the NACE Rev. 2, include the manufacturing of computer, electronic and optical products (26), the manufacturing of electrical equipment (27), the manufacturing of machinery and equipment n.e.c. (28), the manufacturing of motor vehicles, trailers, and semi-trailers (29), and the manufacturing of other transport equipment (30) (Eurostat, 2008). In the literature, no data or statistics are available on a sub-sector level, which is why this chapter on the theoretical background and its statistics focuses on the manufacturing industry overall and does not distinguish between sub-sectors.

To structure the following chapter on the relevance of the CE for the construction and manufacturing industries, a framework developed by Lieder & Rashid (2016) is followed, which defines three main dimensions to be assessed in the context of the CE, namely environmental/waste, resource scarcity and economic benefits (Figure 2).

***Stakeholder: Nations, governmental bodies, society***
Demand on CE: Avoidance and minimisation of environmental impacts
Scope:
- Solid waste and landfill
- Emissions




***Stakeholder: Industrial business enterprises***
Demand on CE: Sustainment and increase of profitability
Scope:
- Business models
- Products design
- Materials
- Supply chains

***Stakeholder: Nations, society***
Demand on CE: Regenerative resource use
Scope:
- Circularity of resources
- Criticality of materials
- Volatility

**Figure 2: Circular Economy framework**[3]

### 2.2.1. Environmental impact

It is difficult to obtain a full and accurate picture of the total waste generated globally. Data oftentimes only focuses on municipal solid waste (MSW) or is not available for some countries/regions at all. However, “a broad grouping of ‘urban’ wastes, including MSW, commercial and industrial (C&I) waste, and construction and demolition waste (C&D), is estimated at around 7 to 10 billion tonnes per annum” (United Nations Environment Programme & International Waste Management Association, 2015, p. 52). With regard to trends in waste generation, it appears that numbers in high-income countries have largely stabilized and, in some countries, even partially decreased. “However, as economies continue to grow rapidly in low- and middle-income countries, one can expect per capita waste generation to increase steadily” (United Nations Environment Programme & International Waste Management Association, 2015, p. 52).

Historically, the construction and manufacturing industries have been among the most polluting industrial sectors. Among all European Union (EU) 27 countries, the construction

[3] Source: Lieder & Rashid (2016, p. 45)

industry alone accounted for 37.5% of all waste generated in 2020 (Figure 3). Although polluting significantly less in comparison, the manufacturing industry still accounted for 10.6% of all waste generated in 2020. This makes it the fourth largest contributor behind the sectors of construction and mining & quarrying (23.4%) and waste/water (10.8%). Interestingly, despite all the attention focused on consumers and individuals by governments, as well as in the literature on CE, households accounted for only 9.4% of the waste generated in the EU-27 (Eurostat, 2023).

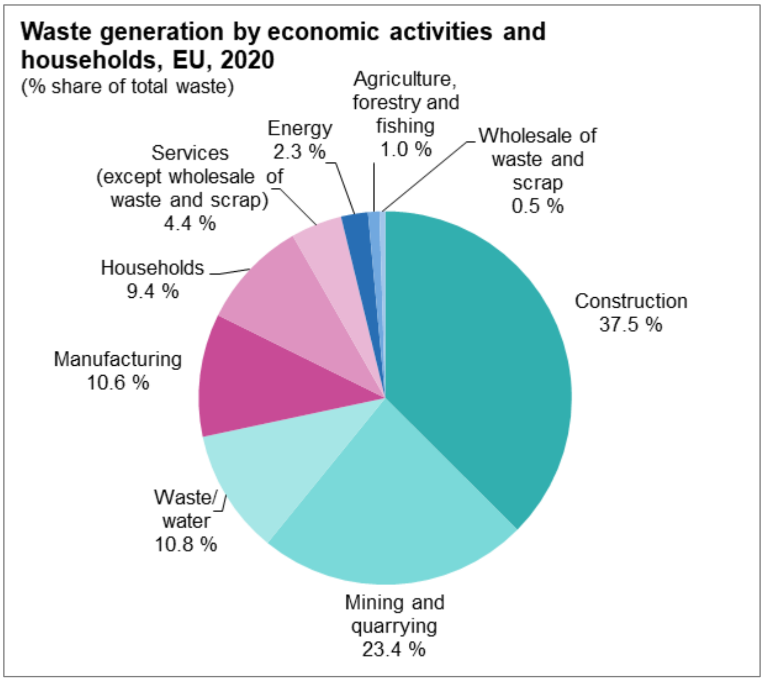



**Figure 3: Waste generation by economic activities and households, EU-27, 2020 (in %)[4]**

### *2.2.1.1. Environmental impact of the construction industry*

In Germany specifically, construction materials make up about 50% of all raw materials extracted (Umweltbundesamt, 2019). At the same time, 54% of the waste generated in Germany in 2021 was C&D waste (Statistisches Bundesamt, 2023), a number significantly higher than the EU average (compare Figure 3).

Recognizing the magnitude of the waste created by the construction sector alone, the EU has formulated clear CE targets for the construction industry as early as in a 2008 directive on

[4] Source: Eurostat (2023, p. 3)

waste. “By 2020, the preparing for re-use [sic], recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material (…) shall be increased to a minimum of 70 % by weight” (Directive 2008/98/EC, 2008). This further highlights the fact that the EU considers CE strategies along the ‘10Rs’ (Potting et al., 2017), such as reuse, recycling, and recovery, as the solution to the waste problem.

At first glance, data from a report from the European Environment Agency (EEA) (2020) from the year 2016 suggests that EU-28[5] countries appeared to be on track to reach these goals by 2020. Some countries were even set to outperform them (Figure 4). The 2016 data suggests that already 82.8% of the mineral part of construction waste is being recycled, with another 5.6% being backfilled and only 11% ending up in landfills (European Environment Agency, 2020).

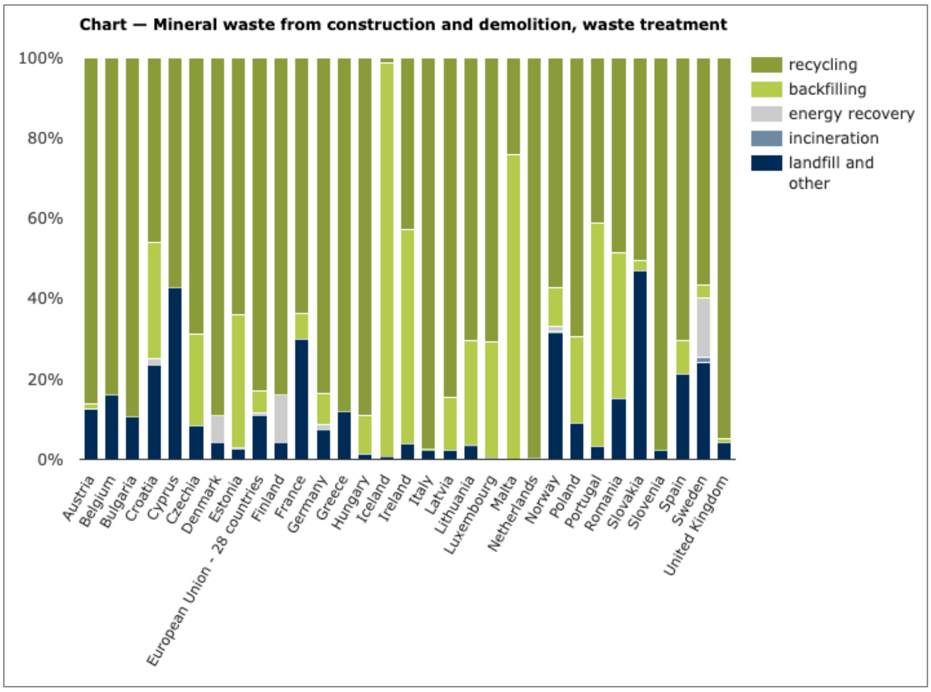



**Figure 4: Waste treatment of the mineral part of waste from construction and demolition in EU-28 (2016)[6]**

[5] Now EU-27 after the United Kingdom left the EU on 31.01.2020.

[6] Source: European Environment Agency (2020)

However, going into more detail, the picture does not look as promising as could be assumed from the reported treatment rates. The EEA report instead states that "material streams arising from demolition and renovation works are not suitable for reuse or closed-loop recycling" (European Environment Agency, 2020, p. 3), mainly due to "building practices in the past and the lack of generation of high-purity materials during demolition" (European Environment Agency, 2020, p. 3).

A significant, additional problem seems to be that many countries only meet the EU targets through backfilling or "low-grade recovery, e.g., using recycled aggregates from the mineral part of C&DW [construction and demolition waste] on applications such as road sub-bases" (European Environment Agency, 2020, p. 3). Going back to the debate on the waste hierarchy and the prioritization of the different 'R' strategies (Directive 2008/98/EC, 2008; Ellen MacArthur Foundation, 2019), it quickly becomes apparent that CE implementation in practice is not as advanced as Figure 4 might suggest at first glance (compare section 2.1.2). As Bocken et al. (2016) correctly argue, primary, secondary, tertiary, and quaternary recycling are inherently different from one another. The use of recycled aggregates for, for example, road sub-bases is effectively a form of downcycling of materials, i.e., a form of secondary recycling, and does not contribute to closing loops for C&D materials. It only slows them down.

Therefore, a closer look at the data suggests that achieving full circularity in the construction sector is still a distant goal. Adams et al. (2017), in their report on CE in the construction industry, go as far as to state that CE thinking in construction is still in its infancy.

Figure 4 also shows that most countries in Europe rely on recycling and backfilling to meet EU targets. Even though recycling of construction and demolition waste is already a step in the right direction, from a CE point of view recycling, especially if it effectively means a form of downcycling, is still far from being a perfect solution. Of course, recycling is preferable to energy recovery or even disposal of waste. Yet, according to the waste hierarchy defined by the European Commission, both waste prevention and reuse are preferable over recycling (Directive 2008/98/EC, 2008). Recognizing the significant amount of waste generated by the construction industry, the complexity of the sector, and the considerable progress that still needs to be made to transition to a Circular Economy, the EU has consequently defined the construction sector as one of its priority areas in its 2015 'Action plan for the Circular Economy' (European Commission, 2015).

There is, however, another aspect to the environmental impact of the construction sector other than waste creation, namely that of greenhouse gas (GHG) emissions. In 2017, the construction and refurbishment of buildings currently accounted for 11% of global energy-related carbon dioxide ($CO_2$) emissions (C40 Cities et al., 2019). Another 28% of global energy-related $CO_2$ emissions are caused by buildings during their operation (International Energy Agency (IEA), 2019). Even though these emissions are not caused by the construction industry directly through, e.g., the use of materials or through activities during the construction process, these emissions, too, are influenced by choices made during the construction phase.

Accounting for 39% of the overall emissions in 2018, this makes the construction and operation of buildings the largest contributor to global energy-related $CO_2$ emissions, even ahead of transport (23%) and any other industry emissions (31%) (International Energy Agency (IEA), 2019, p. 12). Why is this relevant in the context of the CE? It is relevant because CE advocates argue that its implementation can help to reduce GHG emissions. The EMF, for example, argues that fostering CE activities such as sharing and reuse of existing buildings, designing for flexible use and eliminating waste as well as reusing and recycling building materials "could reduce global $CO_2$ emissions from construction and demolition of buildings by 2.1 billion tonnes, by 2050" (Ellen MacArthur Foundation, 2021). Similarly, a recent literature review on the link between the CE and emission reduction in the construction industry finds that "slowing resource loops have demonstrated that substantial GHG savings can be achieved" (Gallego-Schmid et al., 2020, p. 21). The study identifies material reuse as the most promising CE solution (Gallego-Schmid et al., 2020).

##### *2.2.1.2. Environmental impact of the manufacturing industry*

Despite contributing less in relative terms to waste generation in the EU-27 than the construction sector, the manufacturing sector still accounts for 11% of all waste generated in the EU-27 and thus for significantly more than all households combined (Figure 3) (Eurostat, 2023). Therefore, it is not surprising that national governments such as the Netherlands name the manufacturing industry a priority sector alongside the construction industry (Brown et al., 2019). As argued for the construction sector already, transitioning towards a CE can offer means to reduce this waste through CE-specific strategies such as reduction, reuse, recycling, or recovery (the R's) (Directive 2008/98/EC, 2008).

The manufacturing industry is very diverse and encompasses the manufacturing of various products, which eventually contribute to this large amount of waste. As previously mentioned, this dissertation focuses on several subsectors of the manufacturing industry (section 2.2). One of the largest sub-sectors within the overall manufacturing industry, for which data on waste creation is available, is the manufacturing of motor vehicles, trailers, and semi-trailers (29) (Eurostat, 2008). To illustrate the relevance of the CE for the manufacturing industry, this section will focus on the example of this sub-sector, as it gives a good indication of the complexity of the whole manufacturing industry.

Within the subsector of manufacturing of motor vehicles, trailers, and semi-trailers in 2019 alone, 6.1 million passenger cars, vans, and other light goods vehicles were scrapped in the EU, representing a total weight of 6.9 million tonnes (Eurostat, 2022). In light of these numbers, efforts have been made to reduce the proportion of materials that end up as waste, as has been the case in the construction industry. In the EU, a directive on EOL vehicles was introduced as early as September 2000 (Directive 2000/53/EC, 2000). Already at that time, measures were proposed that are now considered core components of the CE. Among them, for example, the call to encourage a "design and production of new vehicles which take into full account and facilitate the dismantling, reuse and recovery, in particular the recycling, of end-of-life vehicles, their components and materials" (Directive 2000/53/EC, 2000, p. 37). Another measure called to increasingly integrate recycled materials to ensure the development of markets for secondary materials (Directive 2000/53/EC, 2000). This shows that, for more than 20 years, the automotive industry, just like the construction industry, has begun to realize that a transition to a CE has the potential to solve the industry's environmental problems.

Data from 2019 indicates that in the European Union, these measures have had some success. Estimates are that 89.6% of the parts of EOL vehicles were reused/recycled (Eurostat, 2022). Whether the material is indeed kept within the loop or whether it is downcycled, as is oftentimes the case in the construction industry, was not reported in the data set. Because recycling rates in the construction industry often significantly overstate the true state of CE progress, as seen in section 2.2.1.1, the data should be taken with a degree of caution.

An aspect that adds additional complexity to the topic of circularity in the manufacturing industry is that many manufactured products, such as vehicles, are often exported at the end of their life. A study from the German Ministry for the Environment, Nature Conservation and Nuclear Safety shows that in 2019, over 3.1 million vehicles were decommissioned in Germany alone. Out of these, only 460,000 were finally decommissioned and therefore eligible for recycling or other EOL treatment. Approximately 2.1 million vehicles were exported as used vehicles to other EU countries, while approximately another 340,000 were exported to non-EU countries (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2019).

Even though at first glance, extending the life of the vehicles would, according to the waste hierarchy of the European Union, be a preferable and more circular solution (Directive 2008/98/EC, 2008), it can also lead to significant additional complexity. This is the case if vehicles are being exported to countries that do not have EOL treatment facilities in place once vehicles reach the end of their next life cycle (Saidini, 2018). As a consequence, although an export of used vehicles can prolong their life cycle in the short term, in the end, it could mean that resources and valuable materials are lost in the long term and that resource loops are ultimately not closed.

### 2.2.2. Resource scarcity

The second dimension of the CE framework by Lieder and Rashid (2016) is that of resource scarcity. Especially companies in resource-intensive industries such as the manufacturing and construction industries are becoming increasingly worried about raw material scarcity and the implications that it could have on their access to critical production parts or materials (European Commission, 2014b).

Data from the German ifo Institute (2022) illustrates these scarcity problems for the construction industry. Material shortages, which were not a concern for the industry for more than 25 years, have begun to occur more often since 2017. They have reached previously unseen heights in 2021 and 2022 in light of the COVID-19 pandemic and the Russian-Ukrainian war (Figure 5). Throughout 2021 and 2022, more than 20% of businesses in Germany, both in building construction and civil engineering, have consistently reported material shortages. In some extreme months, this figure has reached as high as 50% (ifo Institute, 2022).

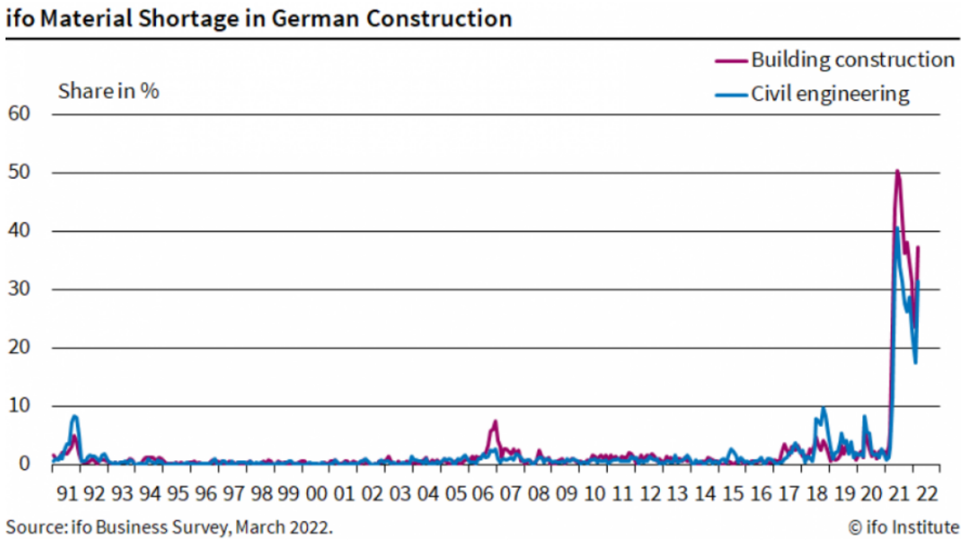



**Figure 5: Material shortage in the German construction industry since 1991**[7]

However, the topic of resource scarcity goes beyond that of accessibility only, as "the discussion about mineral resource depletion is as much about falling resource quality and accessibility as it is about a reduction in resource quantity and availability" (Prior et al., 2011, p. 9). Researchers propose different models to assess the duration that resource reserves on our planet will still last, as they are influenced by many external factors such as population growth, technological advancements, or the exploration of new resource deposits. Still, the core of the discussion remains the fact that the planet's mineral resources are finite (Prior et al., 2011).

As "social prosperity depends on planet earth's finite resource supplies" (Lieder & Rashid, 2016, p. 46), companies are at risk if they cannot access sufficient quantities or sufficient quality of resources for production. If not addressed, this can mean significant risks to their competitiveness. Therefore, The Joint Research Centre of the European Commission lists *aggravating resource scarcity* as one of fourteen megatrends, indicating that it is not only a temporary phenomenon of the last few years but a steadily growing problem for our economy and society (European Commission, 2023a).

Resource scarcity is further aggravated as material demand for some critical raw materials (CRMs) is expected to rise drastically within the near future. Especially copper, lithium, and

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[7] Source: ifo Institute (2022)

nickel are essential materials for the large strategic transformations planned in Germany and the EU overall (e.g., expansion of renewable energies, transition to e-mobility, etc.) (Månberger & Stenqvist, 2018). A recent paper, which reviewed 70 studies providing long-term estimates of demand for metals, concluded that depending on the metal (iron, aluminum, copper, zinc, and nickel), demand is expected to increase 2-6 fold within the span of this century (Watari et al., 2021).

The European Commission initially responded to the threat of resource scarcity in 2014 by defining and assessing the status of CRMs for the first time. CRMs, as determined by the European Commission, include a list of twenty non-energy raw materials such as magnesium or cobalt, but also highly sought-after metals like Gallium, Germanium, and Indium. These are irreplaceable metals for companies in the EU, for which the EU is historically dependent on imports (European Commission, 2014b). In a 2018 update of their CRM report, the European Commission specifically included the Circular Economy as a possible solution to address the criticality of these materials. In fact, the name of the report was changed from *Report on Critical Raw Materials for the EU* (European Commission, 2014b) to *Report on Critical Raw Materials and the Circular Economy* (European Commission, 2018). In the report, the Commission explicitly discusses further actions to reduce leakage from what it defines as 'high-value waste streams' to ultimately reach circularity (European Commission, 2018). These reports laid the foundation for the European *Critical Raw Materials Act*, which provided "a regulatory framework to support the development of domestic capacities and strengthen sustainability and circularity of the critical raw material supply chains in the EU" (European Commission, 2023b). Initially proposed by the European Commission in March 2023, it had not yet entered into force at the time of writing this dissertation.

Similar to the European Commission, academic literature also considers CE a promising strategy to address the problem of increasing resource scarcity. The fact that the CE proposes regenerative design combined with the aspiration to establish closed-loop resource cycles makes it an attractive, if not the only, alternative to the current linear economic system (Lieder & Rashid, 2016). Already in 2018, the European demand for multiple CRMs was partially met by recycling (Figure 6) (European Commission, 2018). In light of external events, such as the aforementioned Russian-Ukrainian war that broke out in early 2022 or the trade conflict between the US and China during the Trump administration, retaining CRMs in the material cycle has become increasingly critical.

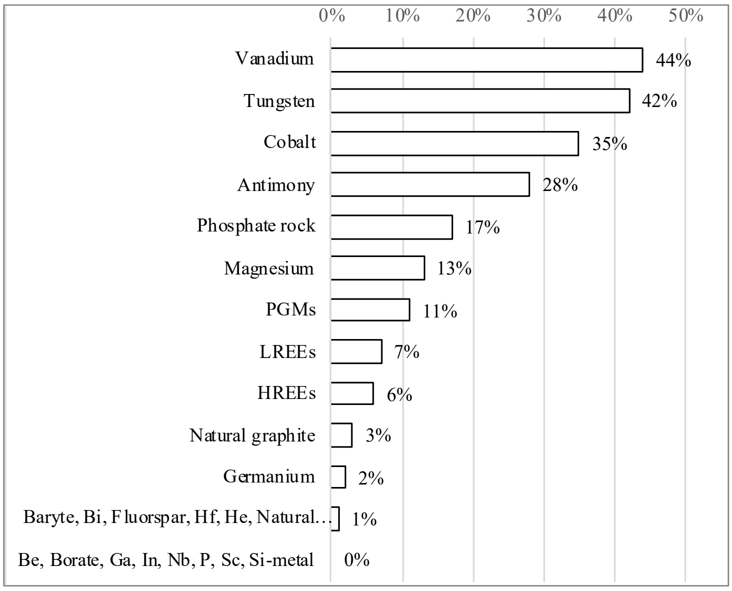


**Figure 6: Contribution of recycling to meet EU demands of CRMs: End-of-Life recycling input rate**[8]

### 2.2.3. Economic benefits

Material shortages can become even more severe when already strained supply chains face additional, unforeseen external events, such as the COVID-19 pandemic or the Russian-Ukrainian war. This can lead to significant price increases for companies dependent on these materials. The German construction industry, for example, experienced a rise in the producer price index for construction materials of 7.2% from May 2020 to May 2021 alone. Specific materials such as bitumen from petroleum (+63.9%), concrete steel bars (+44.3%), or plastic insulation panels (+19.9%) exceeded the average of the index substantially (Statistisches Bundesamt, 2021). Notably, this price increase does not yet reflect any implications of the resource shortages due to the Russian-Ukrainian war, which started in Q1 2022.

These price increases, caused by external events, further accelerate an already increasing price volatility for many materials. In a 2015 report, the EMF states that price volatility for metals in the previous decade had been higher than in any decade of the 20th century (Ellen MacArthur Foundation, 2015a).

[8] Source: European Commission (2018, p. 10)

Increased prices directly impact a firm's profitability and competitiveness. Therefore, resource scarcity can also pose economic risks for companies. Naturally, firms are interested in mitigating these risks. Thus, they consider CE a means to prevent supply shortages of CRMs and other more common materials. As discussed in the previous paragraph, circularity in this context serves a whole different purpose than simply reducing waste creation or a firm's impact on the environment. A circular business model (CBM) can help ensure a firm's autonomy and protect its ability to continue production independently of trade sanctions or other external factors temporarily impacting material supply. This shows that on top of its widely discussed environmental dimension, the CE also has an economic dimension (Ellen MacArthur Foundation, 2015b; Lieder & Rashid, 2016). Already the definition of the CE proposed by Kirchherr et al. (2017) argues that on top of ensuring environmental quality and increased social equity, the CE also leads to economic prosperity.

For individual companies, developing circular products and introducing CBMs not only promises cost advantages but can also offer opportunities on the revenue side. A global consumer survey shows that in the construction industry, 45% of consumers value sustainability as one of their top five purchasing factors. In the category of automotive products, one of the manufacturing sub-sectors examined in this study, the survey reveals that 46% of consumers rank sustainability as one of the top five factors. Of the respondents, 33% and 35% are willing to pay a sustainability premium for construction and automotive products, respectively (Simon Kucher & Partners, 2021).

Therefore, on a macroeconomic level, it is not surprising that, when presented as a new development strategy in China in 2002, the CE was introduced with the explicit goal of ensuring that the Chinese economy could meet both economic and environmental goals (Yuan et al., 2006). Ten years past, the EMF argued that transitioning to a CE could result in a "net material cost saving opportunity of USD 340 to 380 billion p.a. at EU level for a 'transition scenario' and USD 520 to 630 billion p.a. for an "advanced scenario'" (Ellen MacArthur Foundation, 2013, p. 9). Another report by McKinsey & Company suggested "circular-economy principles could (…) generate a net economic benefit of €1.8 trillion by 2030" (McKinsey & Company, 2015) in Europe alone.

It can, therefore, be concluded that the CE also involves an economic dimension, even though "the by far largest share of CE research is done from the perspectives of resource scarcity and environmental impact" (Lieder & Rashid, 2016, p. 39). Other studies confirm this finding and argue that research on the impact of CE principles typically only focuses on the environmental dimension, disregarding its impact on the economic and social dimensions of sustainability (Bjørnbet et al., 2021). A possible explanation could be that "while the benefits for the natural environment are simple to grasp and understand, the economic benefits in the context of CE is [sic] more complex to envisage" (Lieder & Rashid, 2016, pp. 46–47). The previous paragraphs have also clearly shown that all three CE dimensions in the construction and manufacturing industry are closely interrelated and cannot be considered individually.

### 2.2.4. Similarities and differences between the two industries

The previous sections have outlined various similarities between the construction and manufacturing industries. Both industries have significant environmental challenges to solve and are beginning to experience resource scarcity for many CRMs. The CE promises to be a way for both sectors to tackle these issues while at the same time offering significant economic upside potential.

However, there are also notable differences between the two industries. It is important to highlight these differences before delving into research design, data collection, and findings. Arguably, one crucial difference is the composition of the value chain. Figure 7 depicts a simplified circular value chain for the manufacturing industry. In the automotive industry, for example, producers or original equipment manufacturers (OEMs) receive components from their suppliers and design an automobile they then sell to customers. The customers themselves can influence the design (e.g., choose coating, color, (some) interior surface materials, etc.). Still, the product architecture lies within the hands of the producer/OEM.

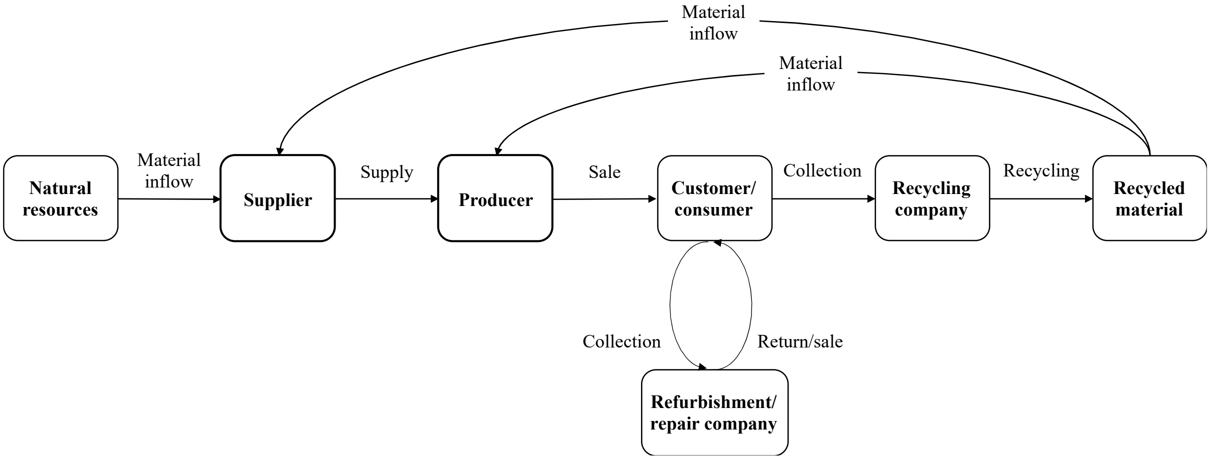


**Figure 7: Circular value chain in the manufacturing industry**[9]

The fact that responsibility for design and architecture is in the hands of OEMs in the manufacturing sector is a key difference in comparison to the construction sector. Producers in the construction industry produce vital components such as steel beams, windows, floors, etc., but the final product, or in other words, the building, is designed and assembled by others. Other than for products in the manufacturing industry, there are architects, structural engineers, developers, and other actors involved in the design and architecture of the end product (Figure 8).

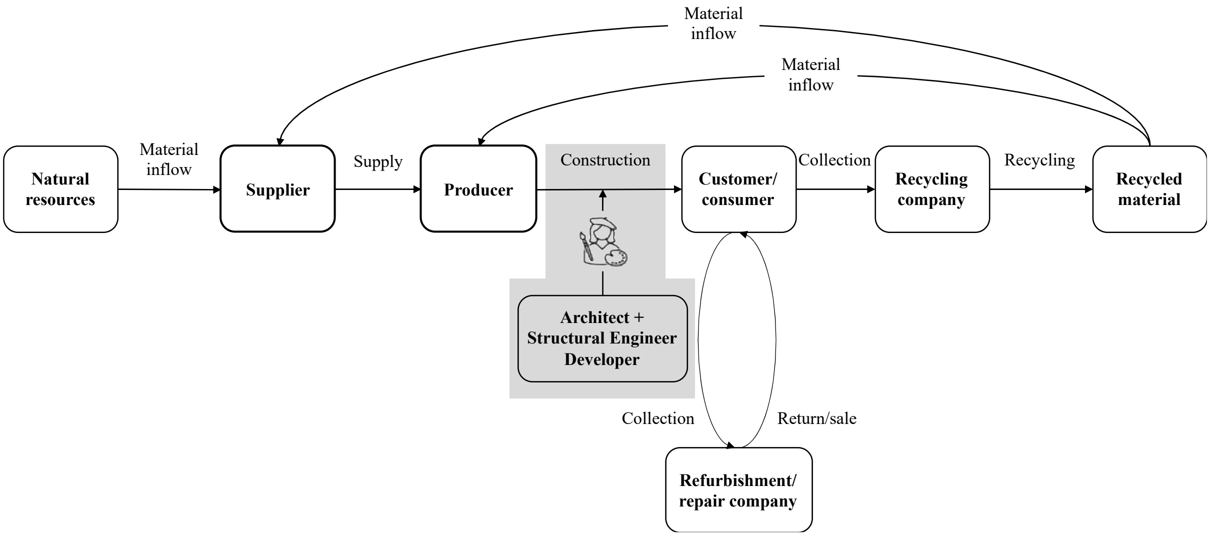


**Figure 8: Circular value chain in the construction industry**[10]

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[9] Source: Author's illustration

[10] Source: Author's illustration

From a CE perspective, the difference between the two industries becomes relevant when it comes to design for reuse, refurbishment, and recycling (DfX). In the manufacturing industry, DfX lies within the hands and responsibility of producers or OEMs. They make decisions on the final material composition and product architecture. Therefore, they can ensure the product follows DfX guidelines.

On the other hand, in the construction industry, producers can only determine DfX criteria for the individual building components they produce. Typically, they have little influence on the recyclability of the final building. Instead, architects, structural engineers, developers, and, to a large extent, end customers, such as homeowners, decide how the end product will look. Therefore, they ultimately also influence whether the building follows DfX criteria. The responsibility, hence, lies within the hands of many instead of the hands of a few, as is the case in the manufacturing industry. In the construction industry this additional layer in the value chain adds complexity and is the reason why, for example, no single-family house exactly resembles another.

### 2.3. Literature review on innovation in the context of the Circular Economy

The research objective and research questions were previously described in section 1.2. This dissertation aims to explore the role of innovation for the implementation of the CE in the construction and manufacturing industries, based on consensus in CE literature that companies need to innovate in various areas of their business to transition to a CE successfully. Therefore, the following section provides an overview of the current research on innovation in the context of the CE.

A definition for the CE has already been provided (section 2.1.2). As is the case for the CE, dozens of definitions have been proposed for *innovation* over the years. This dissertation follows the definition that “an innovation is a new or improved product or process (or a combination thereof) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)” (OECD/Eurostat, 2018, p. 32).

The connection between innovation and sustainability or even, between innovation and CE has been widely discussed in the literature in the last few years. However, as often is the case with emerging research fields, “several terms have been used to connect innovation to environmental concerns, with interrelated, sometimes only slightly distinct, definitions, such as “Environmental innovation” (…) “Sustainable innovation” (…), or “Green innovation” (…)” (de Jesus et al., 2021, p. 2). An example of a concept falling into this category is that of Eco-Innovation (EI), defined as “new or improved socio-technical solutions that preserve resources, mitigate environmental degradation and/or allow recovery of value from substances already in use in the economy” (de Jesus & Mendonça, 2018, p. 77). The proponents of the EI concept argue that “EI can be used as a transformative process to move away from the status quo, to thus create a socio-economic system based on the concept of the CE” (de Jesus & Mendonça, 2018, p. 76).

One of the latest terms introduced in the context of innovation and the CE is collaborative circular-oriented innovation (COI). Today, COI has become a core part of the EU’s strategy for sustainability. It is defined as “the coordinated activities that integrate CE goals, principles, and recovery strategies into technical and market-based innovations, such that the circular products and services that are brought to market purposively maintain product integrity and value capture potential across the full life-cycle” (Brown et al., 2019, p. 3). It is derived from the research field of sustainable oriented innovation (SOI). All these terms might differ slightly from one another; however, all suggest a connection between innovation and sustainability and, in the case of COI, specifically between innovation and the CE.

Several literature reviews have been conducted over the years to summarize research efforts on the connection between the two concepts. Prominent examples include Suchek et al. (2021), de Jesus et al. (2021), and Bocken et al. (2019). They all confirm an increasing research interest in the relationship between the two concepts. Since 2016, the annual number of publications on the topic rose from two (2016) to 14 (2018) and eventually reached 39 (2020). The number of citations on the two concepts followed a similar trajectory during that period (Figure 9) (Suchek et al., 2021, p. 3689). Although the absolute number of publications and citations remains low compared to other areas of management research, the upward trend is clear. This indicates the importance that researchers increasingly attribute to the role of innovation in implementing a CE.

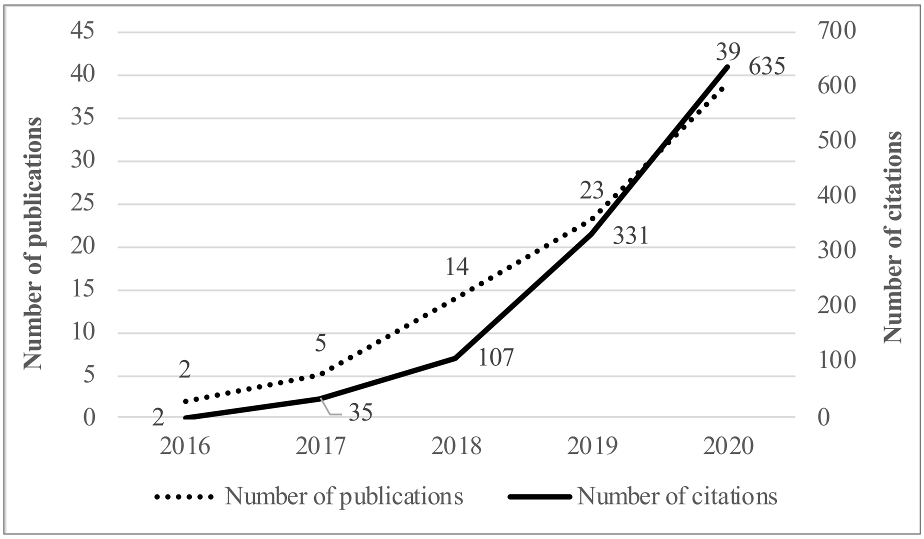



**Figure 9: Annual number of publications and citations on innovation and the CE per year**[11]

The explanation of why research interest in the relationship between the two concepts is increasing appears logical. It has briefly been hinted at in section 1.2 and is rooted in the increasing pressure on individual companies to develop circular products and introduce circular business models. A combination of pressure by law-makers to implement CE principles and meet respective targets and quotas (Directive 2008/98/EC, 2008; Kreislaufwirtschaftsgesetz (KrWG), 2012; European Commission, 2023b), growing demand for sustainable and circular products from consumers (Boyer et al., 2021; White et al., 2019), and increasing resource prices (ifo Institute, 2022) leaves many companies with no other choice than to introduce aspects of circularity in their products For individual firms, this means they need to radically change their products, processes, and business models (Prieto-Sandoval et al., 2018). Such drastic transformations are only achievable through innovation.

*Innovation types*

Schumpeter (1934), laying the basis for the innovation literature as it is known today, identified five different types of innovations: new products, new methods of production, new sources of supply, exploitation of new markets, and new ways to organize the business. As the Circular Economy proposes a shift toward an entirely new economic system, it is unsurprising that its implementation requires innovation along all of these five dimensions. The aforementioned

[11] Source: Suchek et al. (2021, p. 3689)

literature review by de Jesus et al. (2021, p. 11) on innovation and the CE identified various types of innovation in a CE context, including product/service innovation, business model innovation, process innovation, systemic/transformative eco-innovation, organizational innovation, and even marketing innovation.

At the same time, the different types of innovation are not equally relevant for every company at all times. The 10R strategies, described in more detail in section 2.1.2, have shown that individual firms can follow different paths to become more circular. Although researchers argue for a priority order of these strategies (Ellen MacArthur Foundation, 2019; Potting et al., 2017), each of the 10R strategies, such as recycling, remanufacturing, refurbishing, repairing, reusing, and reducing, presents a viable option for a company to contribute to a CE. Depending on the circular strategy chosen by a company, only one or a few of the aforementioned innovation types may become relevant. In existing CE literature, "innovations related to recycling and recovery CE strategies are in the centre of the corpus, along with business-model innovations and systemic/transformative innovations" (de Jesus et al., 2021, p. 17).

Few studies have focused on innovation and the Circular Economy in the specific context of the construction and manufacturing industries. One of the few studies focusing on the manufacturing industry specifically argues that "for manufacturing companies the development of new innovative business models that fit the CE context is vital" (Lieder & Rashid, 2016, p. 47). The same study later argues that on top of business model innovation, product innovation is equally important, as a successful circular business model only reaches operational efficiency if products are designed according to circular standards and with multiple usage phases in mind (Lieder & Rashid, 2016).

*Incremental vs. radical innovation for the CE*

An additional aspect of the discussion on innovation and the CE pertains to the degree of radical innovation required to accelerate the transition to a CE at the firm level. This is linked to the debate from innovation literature on ambidexterity, which is concerned with how firms should balance resources between exploratory and exploitative innovations (Chen, 2017). For context, "exploratory innovations are radical innovations and are designed to meet the needs of emerging customers or markets" (Jansen et al., 2006, p. 1662), whereas "exploitative innovations are incremental innovations and are designed to meet the needs of existing customers or markets" (Jansen et al., 2006, p. 1662).

The previous chapters have already described the challenges and complexities associated with introducing a Circular Economy. Faced with so many challenges, it is unsurprising that previous research argues that "the move to a circular economy model is (…) a radical change, which will require a new way of thinking and doing business. The more radical the technical or product innovation, the more challenging and the greater the likelihood that changes are required to the traditional business model" (Bocken et al., 2016, p. 312). Other researchers echo the call for radical innovation, arguing that "radical innovations in products, processes, and organizations are necessary, as incremental innovation may be susceptible to rebound effects" (Suchek et al., 2021, p. 3697). Further confirming this line of argumentation, a quantitative study conducted in the manufacturing industry in India found that only exploratory innovations had a positive impact on CE adoption, while exploitative innovations had a negative effect (Jakhar et al., 2018). In this way, previous studies seem to be consistent in their emphasis on the importance of exploratory innovation.

At this stage, it is important to recall the industries in focus of this dissertation. Particularly, the construction industry has been described as wary of innovation and risk-adverse on multiple occasions (Hart et al., 2019; Xue et al., 2014). Against this backdrop, it remains to be seen whether an industry that has been less innovative for decades will suddenly be able to introduce the radical innovations required to transition to a CE successfully. It is, therefore, all the more interesting that a recent study concludes that construction firms can experience positive stock market reactions from incremental sustainability innovations and not just radical ones (Duong et al., 2021).

*The need for collaborative innovation and the potential of established innovation concepts*

As the number of publications on innovation in the context of the CE has grown in recent years, there is increasing consensus in the literature that a collaborative approach is necessary for innovation in circular products, processes, and business models. Schmitt and Hansen (2018, p. 27) argue that "circular as compared to conventional innovation requires the intense collaboration of an extended actor set consisting of internal and external constituents." Based on a case study in the manufacturing industry, Konietzko et al. (2020) make a significant contribution in this regard, as they connect the concept of *innovation ecosystems* to the CE, acknowledging the new and extended set of actors required for circular innovations.

The circular value chains, depicted in Figure 7 and Figure 8 for the manufacturing and construction industries, respectively, help to illustrate this further. In a CE, producers interact not only with parts suppliers and customers but also with various other actors, depending on the circular strategies applied. For example, implementing a repair, remanufacturing, or reuse model necessitates communication with the end customer even after the sale. Additionally, it may require the involvement of further actors, such as those responsible for reverse logistics. Similarly, design for recycling (DfR), one of the core components of the C2C concept and an essential prerequisite for a closed-loop CE (McDonough & Braungart, 2002), requires close collaboration between producers and waste treatment companies.

Building upon the insights of how important collaboration is for circular innovations, some researchers have proposed a link to the concept of open innovation. Open innovation is defined as "a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology" (Chesbrough et al., 2006, p. 1). Emphasizing particularly the knowledge sharing (Köhler et al., 2022), stakeholder collaboration, and co-creation aspects of the concept, researchers argue that principles of the open-innovation concept could have the potential to accelerate the transition to a CE (Jesus & Jugend, 2023). Although this connection has not been extensively explored, it presents an intriguing area for future research.

Linking the CE to open innovation is also not the only attempt to connect established streams of innovation literature to the CE concept. Another example is the proposal to connect insights from frugal innovation literature with the CE (Ezeudu et al., 2022). This attempt builds on insights that have proposed the frugal innovation concept as a driver for sustainability overall (Achtelik et al., 2023; Rosca et al., 2018). Arguments why insights from the frugal innovation concept could promote the CE at a firm level are based on the fact that frugal innovations, always in search of more efficient resource utilization, could contribute to decreasing both material requirements and waste generation (Ezeudu et al., 2022). Therefore, the connection primarily addresses the sufficiency and efficiency dimensions of the CE, as noted by Rosca et al., (2018), rather than the effectiveness dimension, which is central to the Cradle to Cradle (C2C) concept.

Frugal innovation and open innovation are just two examples of streams of innovation literature that have recently been proposed to contribute to the implementation of CE at the firm level. However, they are emblematic of the growing interest in the role of innovation for the CE, as well as the increasing attempts to advance the transition through impetus from other research directions.

*Innovation capabilities*

The previous findings from the literature on the relationship between innovation and CE can be summarized as follows: Against a backdrop of ever-increasing pressure to implement CE, the importance attributed to innovation is growing. Given the radicalness of the transition to a CE, exploratory innovation will be necessary at the firm level (Bocken et al., 2016; Suchek et al., 2021). In the manufacturing and construction industries, this can be particularly challenging. Historically, the construction industry, in particular, has been described as cautious of innovation and risk-adverse (Hart et al., 2019; Xue et al., 2014).

The upside for firms looking to implement circular initiatives is that the "process of innovation can be managed, systematized and replicated within organizations" (Lawson & Samson, 2001, p. 378). Firms can learn to manage innovation and can build up competencies and capabilities over time. An essential contribution in the literature in this regard has been the concept of dynamic capabilities, defined as "the subset of the competencies/capabilities which allow the firm to create new products and processes, and respond to changing market circumstances" (Teece & Pisano, 1994, p. 541). In light of the numerous challenges firms are facing on their path to a CE, it is not surprising research has already begun to examine the role of dynamic capabilities in the context of CE implementation (Khan et al., 2020; Köhler et al., 2022; Saari et al., 2023). Some studies even claim that "the development of dynamic organizational capabilities (agility) is more powerful than external pressures as a driver of change toward circularity in terms of circular product innovation and the implementation of circular production processes" (Castro-Lopez et al., 2023, p. 10).

Lawson and Samson (2001) built upon the concept of dynamic capabilities and proposed the concept of innovation capabilities. Suggesting it as the link needed to manage both *mainstream innovation* and *newstream innovation* successfully, they define innovation capabilities as follows: "An innovation capability is therefore defined as the ability to continuously transform knowledge and ideas into new products, processes, and systems for the benefit of the firm and its stakeholders. Innovation capability is not just an ability to be successful at running a business newstream, or to manage mainstream capabilities. Innovation capability is about synthesising these two operating paradigms" (Lawson & Samson, 2001, p. 384). This is precisely what the transition to CE will require from companies in the construction and manufacturing industries. In a CE context, Saari et al. (2023) assessed the impact of innovation capabilities on companies' CE implementation capability, confirming a positive relationship.

For decades, enhancing innovation capabilities or innovativeness, as referred to in some studies, has been on top of the agenda of innovation researchers, not limited to a sustainability or CE context. Significant research has previously examined innovation capabilities in other contexts and what firms can do to enhance them. Several studies in various contexts have identified individual factors such as, for example, the importance of relationship orientation (Panayides, 2006), top managers' innovativeness and their attitude towards innovation (Wang & Dass, 2017), or the openness of firms' innovative search and the inclusion of external sources (Laursen & Salter, 2006), to name just a very few.

In their model of innovation capability, Lawson and Samson (2001) present innovation capability in terms of seven concrete elements rather than as an abstract concept. Figure 10 illustrates the innovation capabilities model and the seven elements: "vision and strategy, harnessing the competence base, organizational intelligence, creativity and idea management, organizational structure and systems, culture and climate, and management of technology" (Lawson & Samson, 2001, p. 388).

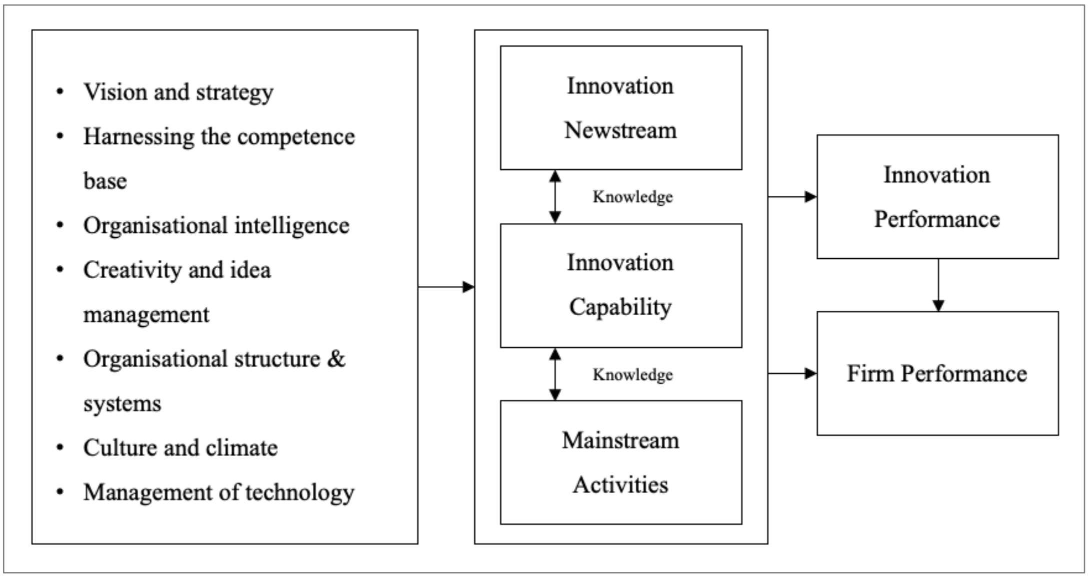



**Figure 10: Model of innovation capability**[12]

Lawson and Samson (2001, p. 380) furthermore argue that "without an understanding of the specific activities underlying capabilities, study replication and knowledge development in the area is difficult". Linking back to the CE, this means that any efforts to improve innovation capabilities in the construction and manufacturing industries require an understanding of specific activities along the seven elements of innovation capabilities.

As far as is known, no previous study in the context of the CE has established a link to Lawson and Samson's (2001) innovation capabilities model. Existing implementation-oriented CE literature focuses more on general enablers (K. T. Adams et al., 2017; Urbinati et al., 2021). This dissertation argues that, despite their practical orientation, those papers remain superficial and lack the level of detail and tangibility for managers to be able to apply the findings at an operational level. There is a clear research gap at this point that needs to be closed, particularly through exploratory research. This dissertation aims to provide the necessary granularity in the context of the CE and examine in detail, which role innovation capabilities play in the CE and how firms looking to implement circular initiatives can enhance their innovation capabilities.

[12] Source: Lawson & Samson (2001, p. 388)

*Summarizing the literature on innovation and the Circular Economy*

The preceding sections have demonstrated that innovation is a fundamental aspect of CE implementation. However, innovation in this context is multifaceted. Over time, various terms such as sustainable innovation, eco-innovation, or circular-oriented innovation have emerged, all emphasizing the significant relevance of innovation for the respective context.

In the context of the CE, multiple studies have identified all types of innovation originally proposed by Schumpeter (1934) as relevant (de Jesus et al., 2021; Prieto-Sandoval et al., 2018). However, their relevance depends on the circular strategy adopted by each individual company. For example, whether a company chooses to offer a reuse model or decides to design for recycling will determine whether product innovation or business model innovation is needed.

As research interest in innovation and the CE has increased steadily in recent years (de Jesus et al., 2021; Suchek et al., 2021), further links between streams of innovation literature (e.g., open innovation, frugal innovation) and the CE are suggested. The question in CE literature seems to be not whether there is a link between innovation and CE but rather what that link looks like concretely.

Luckily for companies, the innovation process can be managed and replicated (Lawson & Samson, 2001). However, as pressure increases to increase CE implementation drastically, so does the need for innovation in the manufacturing and construction industry. Companies operating in the respective sectors must develop the necessary innovation capabilities to navigate the transition to a CE successfully. This is where this dissertation identifies a gap in existing literature.

## 2.4. Derivation of methodological approach

The previous sections have shown that our current linear economic system, with its negative impacts on the environment and its incompatibility with the planet's finite resources, will sooner or later reach its limits. The Circular Economy, proposed as a sustainable, long-term alternative to our linear economic system, has been introduced, its historical development has been described (section 2.1.1), its most essential principles were outlined (section 2.1.2), and it has been defined as a concept (section 2.1.3). An analysis of the current state of CE implementation in Germany has shown that despite its large potential, circularity rates remain low, and waste generation has not significantly decreased from its high levels (section 2.1.4).

Acknowledging the importance of innovation to address this implementation gap, section 2.3 has presented an overview of the existing literature on innovation in the context of the CE. This dissertation derives its research objective from calls for additional research to examine in more detail how innovation can help CE implementation in practice (de Jesus & Mendonça, 2018). Furthermore, a gap in exploratory research on innovation capabilities in a CE context was identified, justifying a deep dive into their role in facilitating this implementation process (section 2.3).

A hybrid approach has been chosen to address this research objective, combining a quantitative study with a subsequent exploratory qualitative study. The purpose of conducting a quantitative survey before the exploratory, interview-based study is to test the significance of the relationships between innovation- and business analysis capabilities and CE implementation as well as CE implementation and firm performance. Despite a focus on innovation capabilities, business analytics capabilities are included in the quantitative study of this dissertation, as business analytics, too, has frequently been presented as a potential accelerator of CE implementation (Kristoffersen et al., 2021b; Liu et al., 2022).

Conducting a quantitative assessment prior to the exploratory qualitative study becomes necessary, given the scarcity of empirical testing of the relationships in the literature. Notable exceptions (Jakhar et al., 2018; Kristoffersen et al., 2021a) have tested the relationships across industries without focusing on a particular sector. To the author's knowledge, the only study to prove the positive impact of CE implementation on firm performance in the manufacturing industry has been Khan et al. (2020). No comparable research for the construction industry is known to the author, i.e., a positive effect of CE implementation on firm performance, at least for the construction industry specifically, has not been established in the literature before.

Therefore, proving the significance of this relationship objectively is crucial to convince firms to intensify their efforts to implement the CE. It is also important to do so before further exploring the role of innovation and innovation capabilities for CE implementation in a qualitative study, as any findings would lose their relevance if a positive correlation between CE implementation and firm performance cannot be proven. Therefore, it was decided to conduct a quantitative study first and test the effect of both innovation- and business analytics capabilities on CE implementation as well as the impact of CE implementation on overall firm performance (chapter 3).

The quantitative study uses established constructs validated in previous research and tests the relationships between the constructs using partial least squares structural equation modeling (PLS-SEM). As a well-established statistical method across research disciplines, structural equation modeling is used to "model and estimate complex relationships among multiple dependent and independent variables" (Hair et al., 2022, p. 4). Therefore, PLS-SEM is the most adequate method to examine the relationships described above and thus answer RQ 1 of this dissertation.

As the quantitative study, as shown later in chapter 3, confirms the relevance of innovation capabilities for CE implementation and the relevance of CE implementation for firm performance, it lays the basis for a second, qualitative study examining the role of innovation capabilities in more detail (chapter 4). The research objective is derived from the insight in the literature on innovation capabilities that states: "Without an understanding of the specific activities underlying capabilities, study replication and knowledge development in the area is difficult" (Lawson & Samson, 2001, p. 380). To discover and understand these specific activities, an exploratory methodology is required. Therefore, the qualitative study uses semi-structured interviews with managers from producers in the construction and manufacturing industries to shed light on the success factors of circular innovations and derive capabilities essential to CE implementation.

The sample for this study consists of CE frontrunners, i.e., firms that have pioneered circular innovations and have introduced circular products or business models. Firms that have obtained certifications for their products, such as the C2C certification, were targeted particularly for the sample, given the rigor of the required certification process. However, as few companies to date, especially in the manufacturing industry, have obtained a C2C certification, the sample includes additional firms whose products nonetheless follow CE principles, as defined in section 2.1.2. A detailed description of the sample and research design follows in section 4.1.

Semi-structured interviews are based on open-ended questions and allow for expanding the questions as the interview evolves to explore newly emerging themes (Makri & Neely, 2021). Given the exploratory nature of the second research question and the novelty of empirical research on concrete innovation capabilities in the context of CE implementation, they are the most promising methodology for the qualitative study, which will be discussed further in chapter 4.

The chosen hybrid approach in this dissertation, which combines a quantitative PLS-SEM study with a second, exploratory, interview-based study, contributes to the growing chapter of implementation-oriented CE research. The insights from the semi-structured interviews, in particular, allow for a level of detail and concreteness in the recommendations on innovation in the context of the CE, as called for by researchers in the past (de Jesus & Mendonça, 2018; Drabe (née Geng) & Herstatt, 2016).

# 3. Quantitative study

## 3.1. Development of hypotheses from the literature

The previous chapter outlined the relevance of the CE for the construction and manufacturing industry in tackling problems on the environmental, resource scarcity, and environmental dimensions (Lieder & Rashid, 2016). In combination with section 2.1.4, it also shows that in many areas, both overall and in the construction and manufacturing sectors in particular, progress in implementing CE is often moderate at best. Given the significant gap that still exists between aspiration and status quo of CE implementation, the question arises of how CE implementation rates can be increased in the short term and the long run.

Shedding light on this question is one of the main goals of this study. The following quantitative study, therefore, attempts to answer RQ 1: *How do innovation – and business analytics capabilities assist firms in the construction and manufacturing industries with CE implementation, and how does CE implementation impact firm performance?* Four constructs are derived from this question, the relationship between which is to be tested in a structural model: business analytics capabilities (BAC), innovation capabilities (ICA), CE implementation (CEI), and firm performance (PER). As section 3.2 will explain in more detail, the four constructs are measured using self-reported data from interview respondents. Therefore, the constructs need to be understood as, for example, 'perceived' CE implementation. Sections 3.1.1 to 3.1.5 will discuss current research on the relationship between the constructs and will subsequently develop the research hypotheses that will then be tested in a structural model.

### 3.1.1. Influence of business analytics capabilities (BAC) on CE implementation (CEI)

Scholars in the research field of CE have argued for and shown that digital technologies and business analytics can be critical enablers for CE implementation (Antikainen et al., 2018; Bressanelli et al., 2018; Kristoffersen et al., 2021a). Before going into detail about the link between the two concepts, it is important to note that the terminology used in the literature is not always consistent. Different concepts such as digitalization, (business-) analytics, big data, and others are used almost interchangeably in CE literature. This dissertation uses the term digital technologies (DT) as an umbrella term summarizing trends such as the Internet of

Things (IoT), Big Data Analytics (BDA), Artificial Intelligence (AI), and 3D-printing (Liu et al., 2022).

Another term used in this section is Circular Economy implementation (CEI). CEI and the progress of CEI on a macroeconomic scale are discussed in sections 2.1 and 2.2. Both sections deal with the degree to which overall economic systems have changed from a linear towards a Circular Economy. In a microeconomic firm context, CEI differs slightly from its definition in a macroeconomic context. Going forward, this dissertation defines CEI in the microeconomic context as the "degree to which a firm effectively leverages circular strategies for value creation and capture as relevant to its perspective" (Bocken et al., 2016; Khan et al., 2020, as cited in Kristoffersen et al., 2021, p. 5). This view of CEI in a microeconomic sense is a centerpiece of the quantitative study conducted in this dissertation.

The application opportunities for DTs to enhance CEI are extensive and encompass various aspects of the CE. "Digitalisation boosts the circular economy business models by helping to close the loop, slow the material loop and narrow the loop with increased resource efficiency" (Antikainen et al., 2018, p. 45). The key reason for this hypothesis is that DTs are "building visibility and intelligence into products and assets such as knowledge of the location, condition and availability of assets" (Antikainen et al., 2018, p. 45), which in turn can facilitate, e.g., predictive maintenance, shared use, or improved recycling (Antikainen et al., 2018).

Delving one level deeper, Liu et al. (2022) identify seven different mechanisms through which digital technologies can enhance the 10Rs[13] of a CE, ranging from digital functions empowering the reverse supply chain to those that support the design, manufacturing, and use of products. The authors present a framework summarizing the findings of their literature review. In this framework, the size of the circles indicates the number of times certain digital functions were mentioned in the literature for any of the 10Rs of the CE (Figure 11). Their findings show that *reducing* is the focus of digital functions, followed by *recycling* and *rethinking*. They also found the majority of applications used for CE activities today fall into

[13] The 10Rs in the context of the CE refer to the circular strategies of refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover (Potting et al., 2017, p. 5).

the category of data analysis and data collection & integration. Automation, on the other hand, currently supports the CE in only a few areas (Liu et al., 2022).

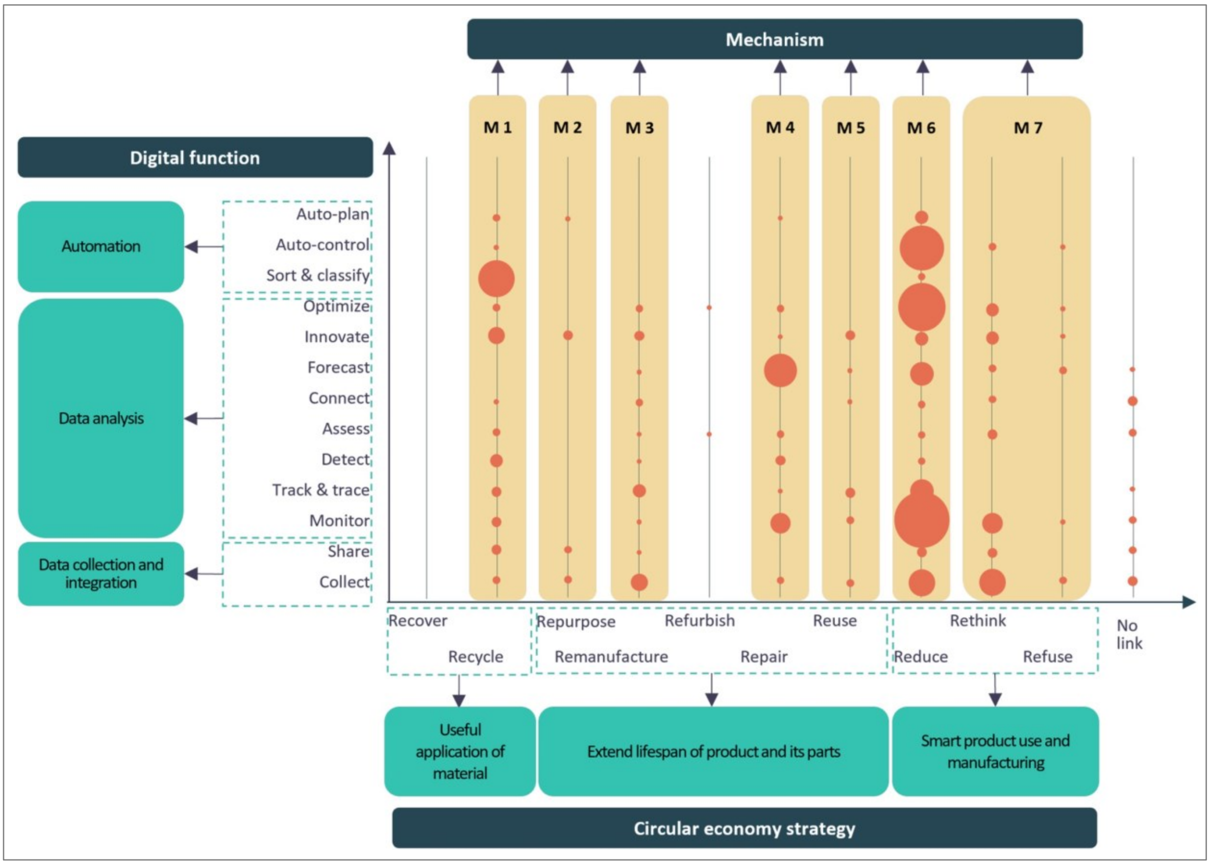



**Figure 11: Framework of digital function for Circular Economy**[14]

Real-world examples demonstrate that links between DTs and CEIs are beginning to emerge not just in niche areas but on a wider scale. For instance, The Ellen MacArthur Foundation (2016) identified several manufacturing companies, such as John Deere, Rolls Royce, and BMW to have implemented DTs to advance circular products or service offerings. As recently as March 2022, the European Commission proposed the Ecodesign for Sustainable Products Regulation (ESPR) to advance the development towards environmental sustainability and circularity of products on a larger scale. All products regulated under the ESPR are to receive a digital product passport, which is designed to "help businesses along the value chain (…) to access information that is valuable in their work to improve environmental performance, prolong product lifetime, boost efficiency and the use of secondary raw materials,

[14] Source: Liu et al. (2022, p. 2182)

thus lowering the need for primary natural resources, saving costs and reducing strategic dependencies" (European Commission, 2022). Nevertheless, despite its apparent potential and the increase of evidence of its application in the field, research indicates that "there remains a gap between the expected, and largely unrealized, potential to use DTs to leverage circular strategies" (Kristoffersen et al., 2020, p. 242).

The concept of business analytics capabilities (BAC) broadly falls under the umbrella term of digital technologies and capabilities but has a slightly different focus. This dissertation supports a definition from Kristoffersen et al. (2021a, p. 5), which defines BAC as "the ability of a firm to effectively mobilize, deploy, and utilize BA [Business Analytics] resources and align BA planning with its strategy to improve its performance". This dissertation focuses on BAC instead of DT, as the construct not only focuses on the availability of resources but also on a company's ability to apply and subsequently leverage them. It thus extends the literature, which to date has mainly focused on the technical implementation of DTs and has, therefore, been criticized by Kristoffersen et al. (2021b). Instead, literature proposes that BAC should also include intangible aspects such as cultural dimensions (e.g., data-driven culture) and human skills (e.g., systems thinking and data science skills) in addition to the purely technical aspects of the concept (Mikalef et al., 2018). Another important difference between the concepts of DT and BAC is that while technologies and tangible resources are easily duplicable by competing firms, it is the capabilities to employ these resources that distinguish a firm from its competitors and create a competitive advantage (Santhanam & Hartono, 2003). Hence, from a theoretical point of view, BAC are significantly more interesting and relevant than the pure availability of tools, technologies, or IT resources.

Research indicates that a growing number of organizations are looking to use BA to speed up their transition to a CE (Kristoffersen et al., 2021b). In the past, researchers have encountered barriers to CE implementation, such as problems with supply chain management (Ritzén & Sandström, 2017), information and data issues in the supply chain (Ghisellini et al., 2018), and a lack of collaboration in the supply chain (Grafström & Aasma, 2021; Guldmann & Huulgaard, 2020). Now, the strength of BA could be a way to overcome some of these barriers. Among its application areas, BA can widely be applied in supply chain management. For example, "big data can be used to better understand how to design supply chain processes, coordinate operations and networks, allow supply chain members to cooperate and engage employees with the circular economy paradigm" (Del Giudice et al., 2020, p. 343).

Similarly, authors argue that "more complex management and planning processes" (Vermunt et al., 2019, p. 893) and related costs (Hansen & Schmitt, 2020) present another barrier to CE implementation. Management research suggests BA already plays a crucial role in supporting management decision processes and strategic planning, potentially leading to better performance (Klatt et al., 2011). Similar to how business analytics might be a way to address some of the supply chain barriers to CE implementation, it may also help to tackle management and planning-related barriers. These are just two examples of the many that demonstrate the intertwined relationship between BAC and CEI, as well as the untapped potential it still holds.

Despite these apparent connections between BAC and CE, literature to date has remained mostly anecdotal (Kristoffersen et al., 2021b). To go beyond the anecdotal evidence, Kristoffersen et al. (2021a) have tested the hypothesis that BAC accelerate CE implementation in their partial least squares structural equation modeling (PLS-SEM) study. They have found BAC "to have to have a significant direct impact on CE implementation ($\beta = 0.770$, $T = 17.738$, $p < 0.001$)" (Kristoffersen et al., 2021a, p. 10). It is important to note, however, that their conclusion from this is "while the development of a BAC is not a prerequisite for CE implementation, it can help organizations generate faster returns and make a more significant impact on their CE investments" (Kristoffersen et al., 2021a, p. 13). In other words, CEI is possible without BAC, but firms with strong business analytics capabilities have a significant advantage when attempting to implement CE initiatives or transition to a CBM.

Based on the previous research discussed in the section above regarding the relationship between BAC and CEI, the initial hypothesis for this study is:

*Hypothesis 1 (H1): Higher levels of perceived BAC have a positive influence on perceived CEI*

### 3.1.2. Influence of innovation capabilities (ICA) on CE implementation (CEI)

As the overall dissertation focuses on examining the role of innovation for the implementation of the CE, section 2.3 has been an extensive literature review of the two concepts and their relationship. To provide clarity on the term innovation capabilities (ICA), going forward, ICA will be defined as "the ability to continuously transform knowledge and ideas into new products, processes and systems for the benefit of the firm and its stakeholders" (Lawson & Samson, 2001, p. 384). The arguments from section 2.3 will not be repeated in this paragraph. However, those arguments and the consensus that innovation is indispensable to achieve the ambitious goals of a Circular Economy are the basis for the hypothesis tested in the following structural model.

One study that takes up the call to test the relationship between innovation and CEI empirically is Jakhar et al. (2018). Their research in the Indian manufacturing industry suggests a positive influence of ICA on the adoption and implementation of CE practices, however, differentiating between exploitative and exploratory innovation capabilities (Jakhar et al., 2018). They only found a statistically significant positive relationship between exploratory innovation capabilities and the adoption of CE practices, and no such relationship was found for exploitative innovation capabilities. In fact, they found exploitative innovation practices to have a statistically significant negative implication for the adoption of CE practices (Jakhar et al., 2018). This provides support for the claim that for a CE, "radical innovations in products, processes, and organizations are necessary, as incremental innovation may be susceptible to rebound effects" (Suchek et al., 2021, p. 3697).

Saari et al. (2023) provide another example of a quantitative assessment confirming the importance of innovation capabilities for CE implementation in the manufacturing and construction industries. Considering the insights from the literature review on the relationship between innovation and the CE (section 2.3) and especially the findings by Saari et al. (2023) and Jakhar et al. (2018), this study hypothesizes:

*Hypothesis 2 (H2): Higher levels of perceived ICA have a positive influence on perceived CEI*

#### 3.1.3. Influence of CE implementation (CEI) on firm performance (PER)

Determining whether the implementation of CE also has an impact on the performance of firms in the construction and manufacturing industry is crucial information, as no one could expect a construction or manufacturing company to implement circular strategies if the data does not suggest a relationship between CEI and company performance. Therefore, testing the effect of CEI on PER, this study will determine if there is an incentive for firms, whose goal in most cases is to improve their performance, to actively invest in CE initiatives.

Before examining the theoretical background to the relationship between CEI and firm performance in more detail, it is necessary to define firm performance. Section 3.4.4 will provide a more detailed discussion of the construct. Still, already at this point, it is worth noting that this dissertation does not take a one-dimensional view of the performance construct as exclusively financial performance, as this view has become more and more challenged in recent years (Richard et al., 2009). Instead, this dissertation adopts the dimensions of financial performance, competitiveness, corporate reputation, and environmental performance, together forming firm performance (Khan et al., 2020; Kristoffersen et al., 2021). Going forward, any discussion on firm performance will, therefore, refer to these four dimensions and not the financial dimension only.

On a macroeconomic level, various actors have argued for a significant economic potential arising from CE implementation (Lieder & Rashid, 2016; McKinsey & Company, 2015). Section 2.2 has already discussed the economic relevance of the CE for the construction and manufacturing industries in a macroeconomic context in more detail. However, the literature suggests that the CE not only has a positive effect on a macroeconomic scale (i.e., for society and the economy as a whole) but also leads to benefits for individual firms. The European Commission, for example, argues that an investment into a well-functioning CE "should improve the global competitiveness of our companies" (European Commission, 2014a, p. 8). Likewise, a report by the Ellen MacArthur Foundation (2015) suggests that businesses will benefit from CE implementation through additional profit opportunities, greater security of supply, new demand for business services (e.g., collection and reverse logistics, remarketing, remanufacturing and refurbishment), as well as improved customer interaction and loyalty.

Academic research further supports these claims from governmental and non-governmental institutions. Antikainen et al. (2018, p. 46), for example, argue that "adapting circular business models enables companies not only to act sustainably, but also to create competitive advantage." Similarly, Lichtenthäler and Neligan (2023, p. 83) have found that firms that have implemented "at least one circular strategy are more successful than the ones without any circular strategy."

Previous empirical studies also confirm a significant positive relationship between CEI and firm performance (PER). "CE implementation does not only improve environmental and financial performance but also competitiveness and corporate reputation" (Khan et al., 2020, p. 3029). They note that financial performance was least improved compared to the other three factors (Khan et al., 2020). Given how implementing new CE initiatives can often be expensive for firms (Tura et al., 2019; Vermunt et al., 2019), and considering the long return on investments they are usually associated with, this is to be expected and will require close evaluation in this dissertation's quantitative assessment.

Kristoffersen et al. (2021a) find a statistically significant, positive impact of CEI on firm performance, noting that CEI also mediates the effect of BAC on firm performance. All this suggests that firms do not need to be intrinsically motivated to contribute to environmental quality or social equity but also profit from CE implementation through increased performance. In other words, CE implementation does not have to be a charitable act, but literature, in fact, suggests a positive influence of CEI on PER. In this context, it needs to be noted that both Khan et al. (2020) and Kristoffersen et al. (2021a) did not focus on a specific industry but evaluated a cross-industry sample in their studies.

These are essential contributions to the CE literature, given that many previous studies on CE barriers have argued that firms are often reluctant to believe in the economic or financial benefits of CE implementation. Various of these barrier studies across industries note "little evidence of financial and environmental benefits" (Guldmann & Huulgaard, 2020, p. 11), an "uncertain return and profit" (de Jesus & Mendonça, 2018, p. 78), or the fact that companies "do not think that the Circular Economy could help them increase the profitability of their business" (Ormazabal et al., 2018, p. 165). For the construction industry specifically, Adams et al. (2017) also identify an unclear financial case as one of the barriers to CE implementation.

These arguments from barrier research are interesting, as they contradict empirical findings such as those by Kristoffersen et al. (2021a) or Khan et al. (2020), who argue that CEI does have a positive influence on performance. It remains to be seen and will be tested in this study if CE implementation does, in fact, impact firm performance in the manufacturing and construction industry. For now, this dissertation decides to follow the empirical evidence from the literature (Khan et al., 2020; Kristoffersen et al., 2021a) and hypothesizes:

*Hypothesis 3 (H3): Higher levels of perceived CEI have a positive influence on perceived PER*

#### 3.1.4. Influence of business analytics capabilities (BAC) on firm performance (PER)

On top of the hypothesized relationship between BAC and CEI (H1), this study also examines the direct relationship between BAC and PER. Business analytics is argued to have four main dimensions, namely to "objectify the decision-making process (…), accelerate the decision-making process (…), improve customer services and the quality of customer marketing (…)" (Yin & Fernandez, 2020, p. 287) and ultimately to help "understand the external environment such as customers and other principal stakeholders“ (Yin & Fernandez, 2020, p. 287). The “capacity to gather, process, structure, and use data in decision-making, known as business analytics, is increasingly seen as a source of competitive advantage” (Kristoffersen et al., 2021b, p. 1). Hence, it appears that, in addition to facilitating CEI, BA might also have a direct positive effect on PER. One of the most cited publications on the topic also argues that “there is convincing evidence that data-driven decision making and big-data technologies substantially improve business performance (Provost & Fawcett, 2013, p. 17).

Several papers have also tested this hypothesis empirically. Important early contributions in this area include Bharadwaj (2000) and Santhanam and Hartono (2003), who find that firms with higher IT capabilities outperform competitors with lower IT capabilities. Similar studies have confirmed these findings. For example, Trkman et al. (2010) find that BAC can affect the performance of an entire supply chain. More recently, Wamba et al. (2017) analyzed the effect of a company’s *big-data analytics capabilities* (BDAC), a concept closely related to BAC, on performance and also confirmed the significant and positive impact of BDAC. Their study also highlighted the importance of *process-oriented dynamic capabilities* as a mediator between BDAC and performance (Wamba et al., 2017). Considering these findings, the relationship between BAC, or the related concepts of IT capabilities, and firm performance can be described as established. Interestingly, another PLS-SEM study by Kristoffersen et al. (2021a) in the specific context of the CE has found the total effect of BAC on performance to be significant, but not the direct relationship of BAC and firm performance, as it was fully mediated by CEI (Kristoffersen et al., 2021a).

Following the insights from the literature and recognizing that the total effect of BAC on performance was ultimately positive in the study by (Kristoffersen et al., 2021a), this study also proposes the hypothesis:

*Hypothesis 4 (H4): Higher levels of perceived BAC have a positive influence on perceived PER*

### 3.1.5. Influence of innovation capabilities (ICA) on firm performance (PER)

Just as this dissertation examines the direct relationship between BAC and PER (H4), it also assesses the direct relationship between ICA and PER. Researchers have argued for the importance of innovation and innovation capabilities for a firm’s competitiveness, profitability, and performance for decades (Ferreira et al., 2020; Veryzer Jr., 1998). Empirical studies have proven that “innovative firms are more profitable and valued at a premium by the share market relative to their less innovative counterparts" (Lawson & Samson, 2001, p. 389). Innovation literature has found significant positive relationships between ICA and PER (Fan et al., 2021; Rajapathirana & Hui, 2018). Lawson and Samson (2001), who have developed the concept of innovation capabilities, argue that "organisations that consciously and explicitly develop and invest in (…) innovation capability, individually and collectively, have a higher likelihood of achieving sustainable innovation outcomes as the engine of their business performance" (Lawson & Samson, 2001, p. 396). Some authors even argue that innovation capabilities might be the most important factor influencing firm performance (Calantone et al., 2002). One can summarize that literature views the positive effect of ICA on PER as established.

Nonetheless, the relationship between ICA and PER is particularly interesting in the context of the manufacturing and construction industry. The construction sector, in particular, has been managed traditionally for decades and has long received relatively little attention in the innovation and management literature despite its importance to the economy (Pries & Janszen, 1995). However, literature suggests this is likely to change as market dynamics change, competition increases, and innovation has become more and more important in the fight for a competitive advantage (Pries & Janszen, 1995). More recent literature suggests that companies in the construction sector have indeed not only begun to innovate on a larger scale but also responded to resource and governmental pressure by introducing sustainable innovation in multiple areas (Duong et al., 2021).

It remains to be seen whether the effect of innovation capabilities on firm performance will a) be mediated through CE implementation and b) be significant in the construction and manufacturing industries, which, in the case of the construction industry in particular, have not been at the forefront of innovation in the past (Pries & Janszen, 1995). Nonetheless, this dissertation hypothesizes:

*Hypothesis 5 (H5): Higher levels of perceived ICA have a positive influence on perceived PER*

### 3.2. Methodology

To test the hypotheses developed in the previous section, the partial least squares structural equation modeling (PLS-SEM) method was chosen. Structural equation modeling (SEM) is a statistical method that allows researchers to "model and estimate complex relationships among multiple dependent and independent variables" (Hair et al., 2022, p. 4). PLS-SEM has been introduced as a causal-predictive technique "to predict and explain a key target construct and/or to identify its relevant antecedent constructs" (Chin et al., 2020, p. 2162). As such, PLS-SEM has the goal to explain the variance of the target construct in a model (e.g., firm performance) through the use of explanatory constructs (e.g., sources of corporate reputation) (Chin, 1998; Hair, Sarstedt, Pieper, et al., 2012).

PLS-SEM has received increasing attention in the literature and is now well-established in several areas of research (Hair et al., 2022). Its application can be commonly found in leading journals in management science, marketing science (Hair, Sarstedt, Ringle, et al., 2012), human resource management (Ringle et al., 2018), and many other disciplines. Various previous studies have also successfully applied the PLS-SEM methodology in CE research (Khan et al., 2020; Kristoffersen et al., 2021a; Tang et al., 2022). Hence, given the nature of this research and the intent to explore whether a causal relationship exists between innovation capabilities, business analytics capabilities, CE implementation, and firm performance, PLS-SEM appears to be the most adequate method to apply to this research question. The path model in this dissertation is estimated and evaluated using the SmartPLS 4 software (Ringle & Wende, 2022).

Hair et al. (2022) propose a systematic, step-by-step procedure for using the PLS-SEM methodology (Figure 12), which this dissertation has also decided to adopt. Hence, the subsequent sections will be structured accordingly.

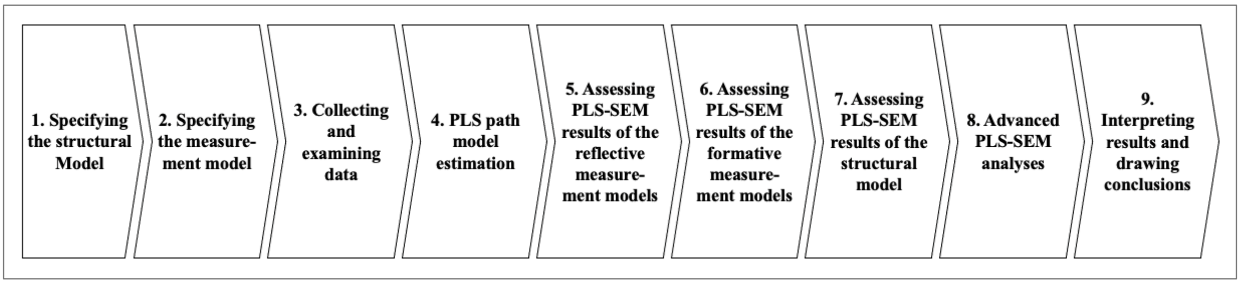



**Figure 12: Procedure for applying PLS-SEM[15]**

## 3.3. Specification of the structural model

A structural model must first be defined to be able to test the hypotheses (H1 to H5) with the PLS-SEM method (Hair et al., 2022). Therefore, the paths in the structural model (Figure 13)

[15] Source: Hair et al. (2022, p. 33)

correspond to the hypotheses derived from the theoretical background in the previous chapter. Within the structural model, business analytics capabilities (BAC) and innovation capabilities (ICA) are the two exogenous constructs. They are the determinants for the two endogenous target constructs of Circular Economy implementation (CEI) and firm performance (PER).

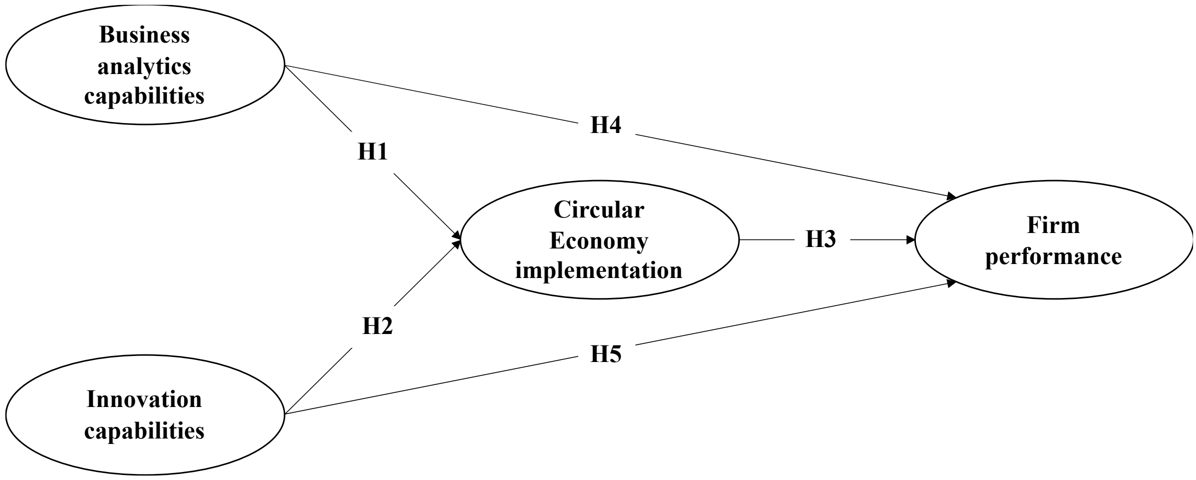



**Figure 13: PLS-SEM structural model**[16]

## 3.4. Specification of the measurement model

To measure each of the four constructs and assess the structural model, each construct requires a measurement model, which is composed of indicator variables that describe it and which can be measured empirically. Typically, such a measurement model is based on previous studies that have validated it (Hair et al., 2022). The following sections will discuss the measurement model of each of the four constructs.

### 3.4.1. Business analytics capabilities (BAC)

The measurement model of the business analytics capability (BAC) construct is based on a construct previously tested by Kristoffersen et al. (2021a) and initially developed by Kristoffersen et al. (2021b). They developed the BAC construct from "eight BA resources (…) that, in combination, build a BAC for CE" (Kristoffersen et al., 2021b). These eight resources argued to constitute BAC are data, technology, basic resources, data-driven culture, circular-oriented innovation (COI) culture, openness and co-creation, systems thinking skills, and data science skills (Kristoffersen et al., 2021b). The construct was subsequently tested and validated

[16] Source: Author's illustration

by Kristoffersen et al. (2021a). Their study used BAC as a third-order construct, measured by the three second-order formative constructs *tangible*, *intangible,* and *human skills,* and eight first-order constructs (Kristoffersen et al., 2021a). These eight first-order constructs represent the eight above-mentioned BA resources identified by Kristoffersen et al. (2021b) and have previously been measured using a total of thirty indicators.

In PLS-SEM literature, such highly complex measurement models, consisting even of third-order constructs, are often criticized, as researchers typically call for PLS-SEM models to be more parsimonious (Hair et al., 2022). Furthermore, adopting the BAC measurement model, as suggested by Kristoffersen et al. (2021a), would mean including thirty indicators for the eight first-order constructs in this dissertation's questionnaire. However, "long surveys are likely to result in respondent fatigue, decreased response rates and an increased number of missing values" (Hair et al., 2022, p. 143). To find a solution that includes all relevant dimensions of BAC and results in a parsimonious model, it was decided to recreate the eight first-order constructs using global single items. A global item is defined as an "item that summarizes the essence of the construct the formative indicators purport to measure" (Hair et al., 2022, p. 144). For example, in this survey, the first-order construct *'data'*, as proposed by Kristoffersen et al. (2021a), was measured with the single indicator *'we have access to high-quality data'* (Table 1). This dissertation's final measurement model of BAC is thus a simplified version of the BAC construct tested by Kristoffersen et al. (2021a). It measures BAC with eight global items instead of thirty indicators while still including the eight relevant BAC dimensions that Kristoffersen et al. (2021b) identified for BAC. This approach circumvents the use of higher-order constructs in the measurement model, making it more parsimonious.

The second relevant aspect to the measurement model of BAC is whether to measure it formatively or reflectively. Even though the initial BAC construct, as tested by (Kristoffersen et al., 2021a), measures BAC formatively, this dissertation argues that, in fact, there is a significant overlap between the indicators of BAC (Table 1). Also, Saari et al. (2022) have assessed a part of the BAC construct (five of the global items) and shown it can be measured reflectively. Therefore, it was ultimately decided to choose a reflective measurement model for BAC in this study.

**Table 1: Indicators of the business analytics capability (BAC) measurement model**

| Construct | Indicator | Question | Source |
|---|---|---|---|
| Business analytics capability (BAC) | BAC1 | We have access to high-quality data | Adapted from: Kristoffersen et al. (2021a); Saari et al. (2023) |
| | BAC2 | We have adequate resources | |
| | BAC3 | We have implemented required technology | |
| | BAC4 | Our managers possess systems thinking skills | |
| | BAC5 | We have data science skills in our company | |
| | BAC6 | We follow a data-driven culture | |
| | BAC7 | Our innovation culture has circular economy objectives | |
| | BAC8 | We promote openness and co-creation | |

### 3.4.2. Innovation capabilities (ICA)

In this dissertation, innovation capability (ICA) is measured reflectively using six indicators (Table 2). Five of these indicators are well-established indicators previously applied and validated by different studies (Fan et al., 2021; Odoom & Mensah, 2019; Saari et al., 2023). One additional item is added to the measurement model of ICA that was previously not included among the five indicators. *'Our company tries to bring new ideas and innovations to the market' (ICA6)* is added from Lin (2007) to emphasize the ability to bring innovations to the market as a crucial part of innovation capabilities. The combined measurement model using all six indicators has been validated by Saari et al. (2023). ICA is measured reflectively, as it has previously been measured in the literature.

**Table 2: Indicators of the innovation capability (ICA) measurement model**

| Construct | Indicator | Question | Source |
|---|---|---|---|
| Innovation capability (ICA) | ICA1 | There is constant generation of new product or service ideas in this firm | Fan et al. (2021); Odoom and Mensah (2019); Saari et al. (2023) |
| | ICA2 | We constantly search for new ways of doing things | |
| | ICA3 | There is creativity in our methods of operation | |
| | ICA4 | This firm is usually a pioneer in the market | |
| | ICA5 | This firm's R&D supports the frequent introduction of new products or services | |
| | ICA6 | Our company tries to bring new ideas and innovations to the market | Lin (2007); Saari et al. (2023) |

### 3.4.3. Circular Economy implementation (CEI)

Like the BAC construct, the CEI construct is based on a measurement model used and validated by Kristoffersen et al. (2021a). CEI has previously been measured "as a second-order formative construct with three first-order formative constructs" (Kristoffersen et al., 2021a, p. 7). These first-order constructs are "reinvent and rethink" (CE-INV), "restore, reduce and avoid" (CE-RRA) and "recirculate" (CE-REC) (Kristoffersen et al., 2021a, p. 7). The original source for the second-order construct was an empirical study by Khan et al. (2020), whereas the indicators and first-order constructs were based on a comprehensive CE framework developed by Blomsma et al. (2019). However, one significant aspect of CE implementation had not been included in the CEI construct as proposed by Kristoffersen et al. (2021a), namely the aspect of design for disassembly. A lack of design for disassembly has been identified as a crucial barrier to CE implementation in several studies and, thus, is an essential component of the CEI construct (Guldmann & Huulgaard, 2020; Hahladakis & Iacovidou, 2019). In this dissertation's measurement model of CEI, the lower-order construct CEI-INV is, therefore, supplemented with an additional fifth item: *'We design for easy disassembly.'* This item is based on an indicator from Jakhar et al. (2018). Otherwise, the CEI measurement model is adopted from Kristoffersen et al. (2021a) (Table 3).

The decision to measure CEI with similar indicators as Kristoffersen et al. (2021a) also means the CEI construct is measured using self-reported data. CEI-RRA1, for example, asks respondents to rate their agreement with the statement: *'We source secondary, recycled and/or renewable materials (e.g., industrial symbiosis, using ocean plastics, non-toxic materials, or biodegradable materials)'* (Blomsma et al., 2019; Kristoffersen et al., 2021a). Therefore, the CEI construct must be understood as 'perceived CE implementation' as it relies on subjective and self-reported data. As pointed out by Kristoffersen et al. (2021a), who used and validated the CEI construct in their study, this leaves a risk of mono-method bias.

An alternative and objective way to measure this indicator could have been to ask respondents for data on the percentage of secondary, recycled, or renewable materials as part of the total materials. However, as Dess & Robinson (1984) have stated, depending on the kind of companies surveyed, it can be difficult, if not impossible, to collect objective data points, especially from privately owned firms. As private firms are desired as part of the sample, subjective indicators, validated by Kristoffersen et al. (2021a), are ultimately used.

**Table 3: Indicators of the Circular Economy implementation (CEI) measurement model**

| Second-order construct | First-order construct | Indicator | Question | Source |
|---|---|---|---|---|
| Circular Economy implemen-tation (CEI) | Reinvent and rethink (CEI-INV) | CEI-INV1 | We provide value offerings that are decoupled from material use (e.g., abandoning physical product for digital service) | Blomsma et al. (2019); Kristoffersen et al. (2021a); Saari et al. (2023) |
| | | CEI-INV2 | We support products during their lifetime through providing spare parts and/or repair services as separate sales offerings | |
| | | CEI-INV3 | We provide the result or performance of a product as a service instead of selling the physical product (e.g., performance-based business models) | |
| | | CEI-INV4 | We provide the access or usage of a product as a service instead of selling the physical product (e.g., usage-based business models) | |
| | | CEI-INV5 | We design for easy disassembly | Jakhar et al. (2018) |
| | Restore, reduce, and avoid (CEI-RRA) | CEI-RRA1 | We source secondary, recycled and/or renewable materials (e.g., industrial symbiosis, using ocean plastics, non-toxic materials, or biodegradable materials) | Blomsma et al. (2019); Kristoffersen et al. (2021a); Saari et al. (2023) |
| | | CEI-RRA2 | We run a lean and clean production (e.g., use less energy and materials, treat wastes, rework) | |
| | | CEI-RRA3 | We optimize product use and operation to extend the product life, minimize energy use, and/ or increase product utilization | |
| | Recirculate (CEI-REC) | CEI-REC1 | We provide activities for extending the existing use-cycles of products and parts (e.g., upgrade, repair, maintenance) | Blomsma et al. (2019); Kristoffersen et al. (2021a); Saari et al. (2023) |
| | | CEI-REC2 | We provide activities for extending products and parts to new use-cycles (e.g., reuse, refurbish, remanufacture) | |
| | | CEI-REC3 | We provide activities for extending the lifespan of materials (e.g., recycle, cascade, energy recovery) | |

### 3.4.4. Firm performance (PER)

As with the CEI construct, a decision on whether to use objective or subjective indicators in the measurement model must also be made for the firm performance (PER) construct. There has been a debate among scholars about how to measure firm performance for decades. Subjective measurements are criticized for their dependency on human cognition and knowledge (Santos & Brito, 2012) and for being "susceptible to bias arising from the availability of recent events" (Richard et al., 2009, p. 726). Objective measures, such as accounting measures, have also been found to be biased, while at the same time often criticized for being influenced by choices on, e.g., "depreciation schedules, inventory, and booking expenses" (Richard et al., 2009, p. 728).

However, as already noted for the CEI construct, one of the most significant disadvantages of objective measures is that data points are often challenging, if not impossible, to collect, especially from private firms. (Dess & Robinson, 1984). Again, as private firms are in the focus of this study, it is difficult to measure the PER construct objectively. Interestingly, Santos and Brito (2012) point out that subjective and objective performance indicators have been proven on multiple occasions to have a significantly positive correlation, suggesting results might not be influenced substantially by this choice.

Although it is the most common and most readily available form of measuring firm performance, research in recent years has started to argue that simply measuring firm performance using objective accounting measures such as returns-on-investment (ROI) or profit margins may not do justice to the complexity of the PER construct (Richard et al., 2009). Other indicators such as "market share, new product introduction, product quality, marketing effectiveness, manufacturing-value added and other measures of technological efficiency" (Venkatraman & Ramanujam, 1986, p. 804) could also be part of a broader conceptualization of business performance.

Since then, concepts such as the triple bottom line (TBL) have emerged. The TBL concept proposes a definition of performance that includes social and environmental performance as additional components on top of the financial aspect (Slaper & Hall, 2011). Other authors propose five different dimensions to measure performance, namely "financial performance, customer satisfaction, employee satisfaction, social performance and environmental performance" (Santos & Brito, 2012, p. 112). Over the years, innumerable further measurement models have been proposed for performance. As the list of authors proposing different dimensions to measure PER increases, it becomes apparent that management and innovation literature scholars have not managed to agree on a single measurement model for firm performance.

Among the dozens of measurement models of firm performance, this dissertation adopts the measurement model used by Kristoffersen et al. (2021a) and Khan et al. (2020), who built the model based on established indicators. In their study, Kristoffersen et al. (2021a) built the firm performance construct “as a second-order formative construct with four first-order formative constructs, specifically environmental performance, financial performance, competitiveness, and corporate reputation” (Kristoffersen et al., 2021a, p. 7). This measurement model recognizes the critique in the literature that financial performance is not enough to measure firm performance (Richard et al., 2009; Santos & Brito, 2012) and includes three additional dimensions. The chosen measurement model has been successfully applied in similar PLS-SEM studies focused on CE implementation. As it performed well in these previous studies, it can be considered as validated (Khan et al., 2020; Kristoffersen et al., 2021a).

##### *3.4.4.1. Testing the measurement model for the PER construct (first run)*

Despite its previous successful application in other studies, it was nevertheless decided to test the PER measurement model before ultimately selecting it for the performance construct (PER). This test evaluates whether the four first-order constructs of perceived environmental performance (PER-EN), perceived financial performance (PER-F), perceived competitiveness (PER-CO), and perceived corporate reputation (PER-CR) are all statistically significant components of the second-order construct PER or whether one of them would not be as relevant as the others.

The proposed model measures PER using the combined indicators of the four constructs PER-CO, PER-CR, PER-EN, and PER-F. Table 4 gives an overview of these indicators. All indicators are measured formatively on a 7-point Likert scale. Sections 3.5 and 3.6 present the rest of the data set in more detail, but for the test of the PER measurement model carried out in this section, these details are not yet of relevance.

**Table 4: Indicators of the firm performance (PER) measurement model**

| Second-order construct | First-order construct | Indicator | Question | Source |
|---|---|---|---|---|
| Firm performance (PER) | Environmental performance (PER-EN) | PER-EN1 | We reduced energy consumption. | Khan et al. (2020); Kristoffersen et al. (2021a); Saari et al. (2023) |
| | | PER-EN2 | We reduced waste generation. | |
| | | PER-EN3 | We reduced atmospheric pollution. | |
| | Financial performance (PER-F) | PER-F1 | We decreased manufacturing/operational costs. | |
| | | PER-F2 | We increased annual turnover. | |
| | | PER-F3 | We increased market share. | |
| | Competitiveness (PER-CO) | PER-CO1 | We increased capability to introduce innovative products/services. | |
| | | PER-CO2 | We improved quality of products/services. | |
| | | PER-CO3 | We improved brand value of products/ services. | |
| | | PER-CO4 | We increased accessibility to new markets. | |
| | Corporate reputation (PER-CR) | PER-CR1 | We improved corporate image among customers. | |
| | | PER-CR2 | We improved relationship with suppliers/ local community/ regulatory organization. | |
| | | PER-CR3 | We increased satisfaction and support from investors/partners. | |
| | | PER-CR4 | We increased satisfaction and loyalty of employees. | |

In the first run of the PLS-SEM algorithm, the inner-variance inflation factor (VIF) value for the lower-order construct PER-CO indicated a collinearity issue when evaluating the structural model. A collinearity issue exists when one of the VIF values exceeds the threshold of 5.0 (Hair et al., 2022). As Table 5 shows, this issue appeared for PER-CO.

Following the recommendations of Hair et al. (2022), one of the PER-CO indicators was therefore excluded from the measurement model to address the collinearity issue. As PER-CO4 (‘*we increased accessibility to new markets’)* was not significant in the first run of the model, it was decided to exclude this indicator from the measurement model. The PLS-SEM algorithm was then run a second time without the indicator PER-CO4.

**Table 5: Collinearity assessment of the formative measurement model (inner model)**

| | PER | PER-CO | PER-CR | PER-EN | PER-F |
|---|---|---|---|---|---|
| **PER** | | | | | |
| **PER-CO** | 5.029 | | | | |
| **PER-CR** | 3.592 | | | | |
| **PER-EN** | 2.549 | | | | |
| **PER-F** | 3.269 | | | | |

### *3.4.4.2. Testing the measurement model for the PER construct (second run)*

*Assessment of the formative measurement model:* During the second run of the model, an assessment of the outer VIF values shows no indicators with collinearity issues. All indicators are below the threshold of 5.0, and except for PER-CO3, all indicators are even below the value of 4.0 (Table 6) (Hair et al., 2022).

**Table 6: Collinearity assessment of the formative measurement model (outer model)**

| Indicator (1/2) | VIF (1/2) | Indicator (2/2) | VIF (2/2) |
|---|---|---|---|
| **PER-CO1** | 3.162 | **PER-EN1** | 2.038 |
| **PER-CO1** | 2.279 | **PER-EN1** | 1.826 |
| **PER-CO2** | 3.658 | **PER-EN2** | 2.739 |
| **PER-CO2** | 2.965 | **PER-EN2** | 2.205 |
| **PER-CO3** | 2.747 | **PER-EN3** | 3.150 |
| **PER-CO3** | 4.152 | **PER-EN3** | 2.436 |
| **PER-CR1** | 1.842 | **PER-F1** | 2.516 |
| **PER-CR1** | 2.252 | **PER-F1** | 1.368 |
| **PER-CR2** | 1.946 | **PER-F2** | 1.753 |
| **PER-CR2** | 2.292 | **PER-F2** | 1.940 |
| **PER-CR3** | 2.695 | **PER-F3** | 3.399 |
| **PER-CR3** | 2.114 | **PER-F3** | 1.984 |
| **PER-CR4** | 2.500 | | |

The results of the bootstrapping procedure show that, except for PER-EN1 and PER-F2, all formative indicators are statistically significant at the 5% level (Table 7). However, both PER-EN1 and PER-F2 have outer loadings >0.5, which justifies keeping them in the measurement model (Hair et al., 2022).

**Table 7: Significance testing results of the outer weights of the formative constructs**

| Formative constructs | Formative indicators | Outer weights (outer loadings) | T statistics (\|O/STDEV\|) | p-values | 95% percentile confidence interval | Significance ($p < 0.05$)? |
|---|---|---|---|---|---|---|
| **PER-CO** | **PER-CO1** | 0.291 (0.858) | 3.638 | 0.000 | (0.141, 0.452) | Yes |
| | **PER-CO2** | 0.304 (0.904) | 4.015 | 0.000 | (0.153, 0.449) | Yes |
| | **PER-CO3** | 0.506 (0.941) | 5.715 | 0.000 | (0.322, 0.670) | Yes |
| **PER-CR** | **PER-CR1** | 0.264 (0.806) | 3.183 | 0.001 | (0.100, 0.425) | Yes |
| | **PER-CR2** | 0.339 (0.850) | 3.597 | 0.000 | (0.153, 0.524) | Yes |
| | **PER-CR3** | 0.301 (0.849) | 4.413 | 0.000 | (0.160, 0.427) | Yes |
| | **PER-CR4** | 0.288 (0.844) | 4.441 | 0.000 | (0.161, 0.414) | Yes |
| **PER-EN** | **PER-EN1** | 0.166 (0.757) | 1.538 | 0.124 | (-0.034, 0.390) | No |
| | **PER-EN2** | 0.422 (0.900) | 4.811 | 0.000 | (0.240, 0.587) | Yes |
| | **PER-EN3** | 0.527 (0.938) | 5.214 | 0.000 | (0.314, 0.714) | Yes |
| **PER-F** | **PER-F1** | 0.640 (0.901) | 8.440 | 0.000 | (0.480, 0.773) | Yes |
| | **PER-F2** | 0.036 (0.608) | 0.529 | 0.597 | (-0.093, 0.176) | No |
| | **PER-F3** | 0.482 (0.832) | 6.541 | 0.000 | (0.340, 0.626) | Yes |
| **PER** | **PER-CO1** | 0.084 (0.809) | 3.362 | 0.001 | (0.040, 0.137) | Yes |
| | **PER-CO2** | 0.087 (0.852) | 3.894 | 0.000 | (0.044, 0.133) | Yes |
| | **PER-CO3** | 0.145 (0.888) | 5.202 | 0.000 | (0.093, 0.203) | Yes |
| | **PER-CR1** | 0.091 (0.744) | 3.164 | 0.002 | (0.035, 0.148) | Yes |
| | **PER-CR2** | 0.117 (0.784) | 3.512 | 0.000 | (0.052, 0.184) | Yes |
| | **PER-CR3** | 0.104 (0.783) | 4.209 | 0.000 | (0.055, 0.152) | Yes |
| | **PER-CR4** | 0.100 (0.779) | 4.368 | 0.000 | (0.056, 0.145) | Yes |
| | **PER-EN1** | 0.037 (0.648) | 1.520 | 0.129 | (-0.008, 0.089) | No |
| | **PER-EN2** | 0.095 (0.770) | 4.263 | 0.000 | (0.051, 0.139) | Yes |
| | **PER-EN3** | 0.119 (0.803) | 4.967 | 0.000 | (0.070, 0.164) | Yes |
| | **PER-F1** | 0.156 (0.806) | 7.498 | 0.000 | (0.112, 0.194) | Yes |
| | **PER-F2** | 0.009 (0.544) | 0.531 | 0.596 | (-0.022, 0.043) | No |
| | **PER-F3** | 0.117 (0.744) | 6.475 | 0.000 | (0.081, 0.153) | Yes |

*Assessment of the structural model:* Most importantly, other than in the first run of the measurement model, the inner VIF values now show no value above the threshold of 5.0 (Table 8). The exclusion of the indicator PER-CO4 solves the collinearity issue for the PER-CO construct. The VIF value for PER-CO is now <5.0, which is an acceptable value (Hair et al., 2022).

**Table 8: Collinearity assessment of the formative measurement model (inner model)**

| | PER | PER-CO | PER-CR | PER-EN | PER-F |
|---|---|---|---|---|---|
| **PER** | | | | | |
| **PER-CO** | 4.972 | | | | |
| **PER-CR** | 3.588 | | | | |
| **PER-EN** | 2.560 | | | | |
| **PER-F** | 3.263 | | | | |

The bootstrapping results for the PER model demonstrate that all four lower-order constructs (PER-EN, PER-F, PER-CO, PER-CR) positively impact perceived performance (PER) and exhibit p-values below 0.05, which means that they are all statistically significant at the 5% level (Figure 14). Corporate reputation (PER-CR) has a path coefficient of 0.346 and appears to have a slightly higher influence on perceived performance than the other three. All other three constructs show similar path coefficients in the range of 0.287 (PER-CO) to 0.225 (PER-EN). This is an important finding, as it indicates that all four performance dimensions are relevant and should be included in the overall measurement model for PER. Measuring PER with only one of these dimensions (e.g., only with financial performance (PER-F)) would not capture the entire essence of the performance construct. This is in line with the findings of the theoretical discussion presented earlier, which also argues for the inclusion of items other than purely financial ones and confirms the approach taken by Kristoffersen et al. (2021a). Therefore, the measurement model described above will be used for the PER construct in the larger structural model. PER is established as a formative second-order construct measured by PER-EN, PER-F, PER-CO, and PER-CR, which themselves are measured as formative first-order constructs.

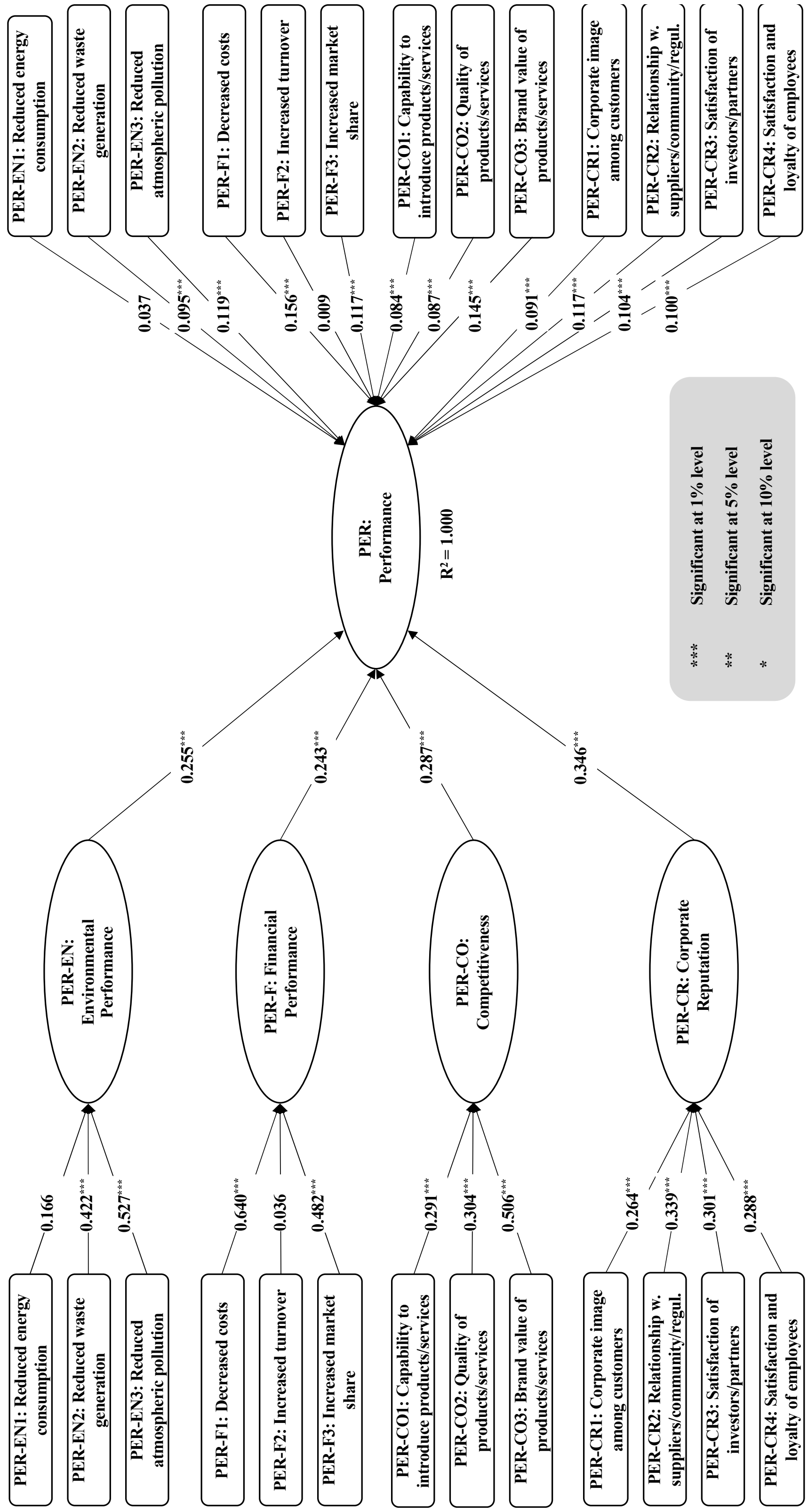



**Figure 14: Bootstrapping results (path coefficients and p-values) of the PER model[17]**

[17] Source: Author's illustration of the PLS-SEM results; constructs based on Khan et al. (2020); Kristoffersen et al. (2021a); Saari et al. (2023)

### 3.5. Research design and data collection process

After specifying the structural and measurement models, the next step of applying PLS-SEM involves collecting and analyzing the data. Data collection took place in December 2021 and January 2022. The process was partially assisted by a professional market research company, which supported the reach-out to respondents. The Finnish Academy of Science research and innovation program (grant agreement No. 337722) granted funding for this study. The survey targeted employees of companies working in the German construction and manufacturing industries as classified according to the NACE Rev. 2, the *Statistical classification of economic activities in the European Community* (section 2.2) (Eurostat, 2008).

The questionnaire was developed together with Dr. Ulla Saari of Tampere University, Finland and in close collaboration with Prof. Dr. C. M. Ringle of the Institute of Human Resource Management and Organizations (HRMO) at TU Hamburg. Respondents were asked to rate their perceptions of their company's business analytics capability (BAC), innovation capability (ICA), circular economy implementation (CEI), and firm performance (PER). Additionally, the questionnaire included thirteen control variables.

The items to measure the constructs in the measurement model are assessed using a 7-point Likert scale ranging from *'do not agree at all'* to *'fully agree'*. The questionnaire provided respondents with the option to select *'I do not know'* to account for the possibility that some respondents may not possess the knowledge to answer all of the questions. In case they do not have expertise in certain areas, the use of this option, therefore, ensures respondents are not forced to pick an answer. It is expected that this decision improves the overall quality of the data, despite a risk that some responses might have to be excluded due to too many *'I do not know'* answers.

The survey was conducted in German, and all items were translated from English to German. Two researchers at the Institute for Technology and Innovation Management (TIM) at TU Hamburg checked and verified the translation before it was sent out (see Appendix A for the questionnaire sent out to participants (in German)). In total, 258 complete responses were received across the two industries of interest. These responses were then quality-checked to exclude bad-quality responses that could negatively impact the results of the PLS-SEM analysis. Such bad-quality answers included one-liners (respondents who always selected the same answer), speedsters (respondents who took an unrealistically short time to answer the questionnaire), and those that had >15% missing answers or *'I do not know'* answers (Hair et al., 2022). 81 respondents were excluded due to such poor-quality answers. The final sample ultimately includes n = 177 responses.

### 3.6. Description of the final data set

Below, Table 9 presents a descriptive overview of the sample (n = 177) that makes up the final data set. This section picks up some of the most interesting statistics and describes them in more detail.

**Table 9: Selected sample characteristics**

| | Sample (n = 177) | Percentage (%) |
|---|---|---|
| **Industry** | | |
| Construction | 90 | 51% |
| Manufacturing | | |
| Manufacturing of machinery and equipment n.e.c. | 48 | 27% |
| Manufacturing of computer, electronic and optical products | 20 | 11% |
| Manufacturing of electrical equipment | 2 | 1% |
| Manufacturing of other transport equipment | 14 | 8% |
| Manufacturing of motor vehicles, trailers, and semi-trailers | 3 | 2% |
| **Number of employees** | | |
| 1–9 | 24 | 14% |
| 10–49 | 43 | 24% |
| 50–249 | 41 | 23% |
| 250-500 | 20 | 11% |
| >500 | 49 | 28% |
| **Age of company** | | |
| <1 year | 3 | 2% |
| 1-4 years | 2 | 1% |
| 5-9 years | 13 | 7% |
| 10-49 years | 98 | 55% |
| 50+ years | 61 | 34% |
| **Years business analytics employed** | | |
| We do not employ business analytics | 38 | 21% |
| <1 year | 14 | 8% |
| 1-3 years | 38 | 21% |
| 3-5 years | 36 | 20% |
| 5+ years | 51 | 29% |
| **Years worked with the CE** | | |
| We do not work with the Circular Economy | 41 | 23% |
| <1 year | 15 | 8% |
| 1-3 years | 46 | 26% |
| 3-5 years | 44 | 25% |
| 5+ years | 31 | 18% |
| **CE as part of the company strategy** | | |
| Not at all part of our strategy | 48 | 27% |
| A part of our overall strategy | 119 | 67% |
| One of the core points of our strategy | 10 | 6% |

**Table 9: Selected sample characteristics (cont.)**

| | Sample (n = 177) | Percentage (%) |
|---|---|---|
| **Ownership structure** | | |
| Publicly owned | 22 | 12% |
| Family owned | 62 | 35% |
| Privately owned | 85 | 48% |
| State-owned | 8 | 5% |
| **Position** | | |
| Manager (other) | 31 | 18% |
| (Skilled) Worker/Craftsman | 29 | 16% |
| Employee (other) | 19 | 11% |
| Purchasing Manager | 13 | 7% |
| Process Manager | 12 | 7% |
| Operations Manager | 9 | 5% |
| Product Designer | 8 | 5% |
| Procurement Manager | 7 | 4% |
| Process Developer | 7 | 4% |
| Office Worker (other) | 7 | 4% |
| CEO/President | 6 | 3% |
| IT Manager | 6 | 3% |
| Marketing Manager | 5 | 3% |
| Director | 4 | 2% |
| Student/Apprentice | 4 | 2% |
| Project Leader | 3 | 2% |
| CIO | 2 | 1% |
| Accountant | 2 | 1% |
| Engineer (other) | 2 | 1% |
| Head of Digital Strategy | 1 | 1% |
| **Gender** | | |
| Male | 125 | 71% |
| Female | 52 | 29% |
| **Age** | | |
| 18-24 | 8 | 5% |
| 25-34 | 43 | 24% |
| 35-44 | 31 | 18% |
| 45-54 | 45 | 25% |
| 55-64 | 48 | 27% |
| 65 and above | 2 | 1% |

*Key statistics of the data set*

Out of all answers in the sample, 51% (n = 90) come from the construction industry, while 49% of respondents come from the manufacturing industry (n = 87). 61% (n = 108) of the answers were given by employees of small and medium-sized enterprises (SMEs) (<250 employees). In comparison, 11% (n = 20) of respondents work in companies between 250 and 500 employees, and another 28% (n = 49) are employed in companies larger than 500 employees (Figure 15).

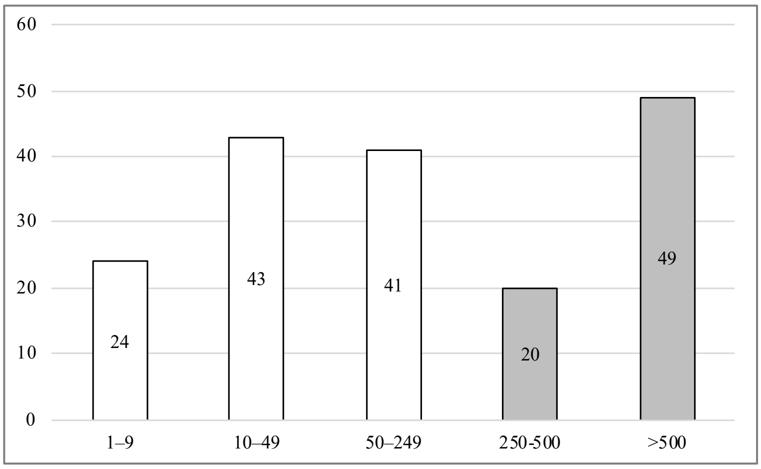



**Figure 15: Size of company in the final sample by number of employees (absolute)[18]**

Of all respondents, 6% (n = 10) indicate that the CE is a core component of their company's overall strategy. Conversely, 27% (n = 48) of respondents indicate that the CE is currently not a part of their company's strategy. Interestingly, companies appear to differ in terms of the extent to which circularity is part of their strategy, both in terms of company size and industry. 63% (n = 15) of the companies with nine or fewer employees indicate the CE was '*not at all part of our strategy*' (Figure 16). Among the companies with 250-500 employees, 85% (n = 17) indicate the CE is at least "a part of our overall strategy", while only 15% (n = 3) say it is not at all part of the strategy. Among companies with more than 500 employees, as little as 8% (n = 4) say that the CE is not part of their strategic objectives at all, while 92% (n = 45) indicate it is either a part or one of the core points of their strategy. Larger companies appear to have embedded the CE in their company's objectives more often.

[18] Source: Author's illustration

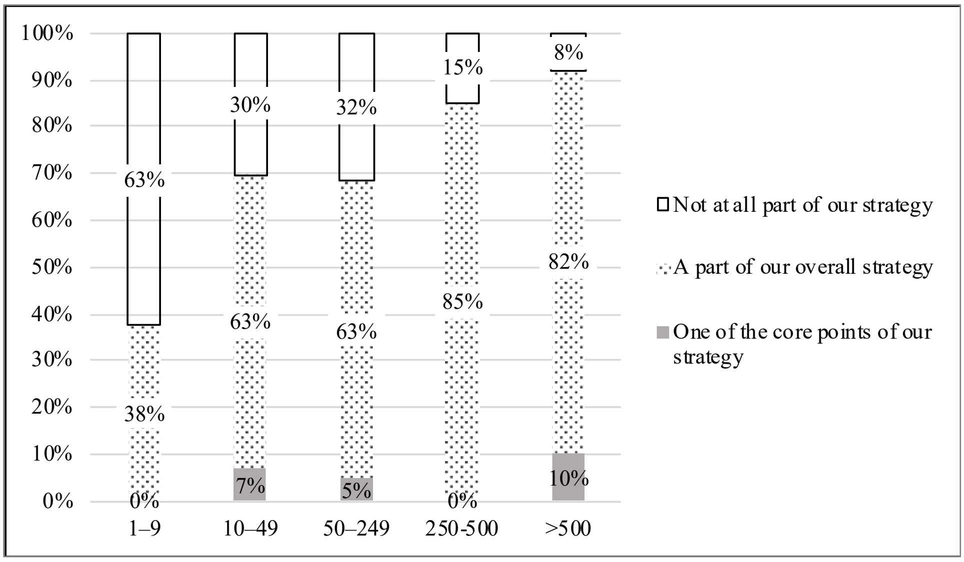



**Figure 16: Answers to the question: 'To what extend is the CE part of the strategy of your company?' by size of the company (in %)**[19]

Differences also become apparent when comparing the construction and the manufacturing industry. 80% (n = 70) of the respondents in the manufacturing industry indicate that the CE is either a part or one of the core points of their company's strategy. Only 20% (n = 17) of the respondents indicate it is not part of their company's strategy. This number is 50% higher in the construction industry, where 34% (n = 31) of the respondents state that the CE is not part of the company's strategy. In comparison to 80% in the manufacturing industry, only 66% of respondents in the construction industry state that the CE is "a part of our overall strategy" (61%) or "one of the core points of our strategy" (4%) (Figure 17).

[19] Source: Author's illustration

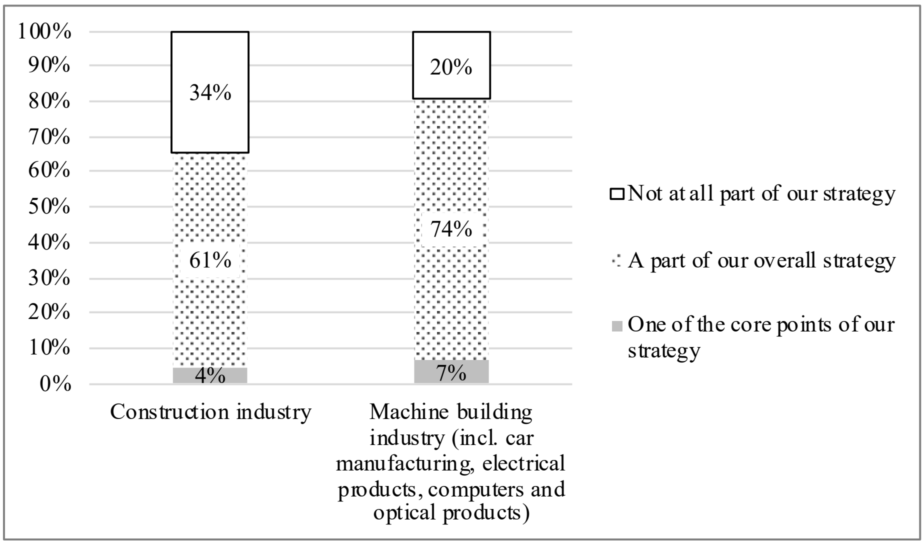



**Figure 17: Answers to the question: 'To what extend is the CE part of the strategy of your company?' by industry (in %)[20]**

*Minimum sample size*

The minimum sample size is another critical aspect of the data that needs to be assessed before conducting a PLS-SEM analysis. Although PLS-SEM can work better with small sample sizes than other statistical methods, it is essential that a small sample size should not be the reason for selecting the PLS-SEM method, even though this is an argument frequently brought forward by other researchers (Hair et al., 2022). A commonly used approach to assess the minimum sample size of a data set is the so-called ten times rule, "which suggests the sample size should be equal to 10 times the number of independent variables in the most complex regression on the PLS[21] path model" (Hair et al., 2022, p. 25). This method, however, is criticized quite heavily in the literature, which is why Kock and Hadaya (2018) proposed the inverse square root method instead. When applying this method, Hair et al. (2022) suggest drawing on previous models in a similar research field to proactively determine the minimum sample size prior to data analysis. As argued before, Kristoffersen et al. (2021a) conducted a similar study in the area of CE implementation, in which the smallest significant path coefficient had a value of 0.253. Using the inverse square root method based on this value and a 5% significance level, the minimum sample size is 97. Therefore, the sample size of 177,

[20] Source: Author's illustration

[21] Partial Least Squares (PLS)

which is the size of the data set in this dissertation, meets the minimum sample size requirements.

*Missing values treatment*

As briefly mentioned in section 3.5, to guarantee a higher data quality, respondents are not forced to answer the questions had the option to choose *'I do not know'.* In the data set, the *'I do not know'* answers are treated as missing values. As suggested by Hair et al. (2022), all responses with 15% or more missing or *'I do not know'* answers are excluded from the data set. As a result, 21 responses have been excluded from the sample as the respondents could not answer more than 85% of the questions, indicating a lack of expertise.

On the indicator level, Hair et al. (2022) argue that any indicator with >15% of missing data should be excluded from the measurement model. Looking at the data, the maximum number of missing values per indicator is 10, which translates to 5.6% of answers missing. This means no indicator needs to be removed from the measurement model, and the study can continue with the measurement models specified in sections 3.4.1 to 3.4.4.

The next important decision is how to treat the remaining missing values in the data set. After excluding all responses with >15% of missing values, 171 missing values remain in the data set, equalling 1.5% of total values. The three most common strategies for missing values are mean value replacement, casewise deletion/listwise deletion, and pairwise deletion (Hair et al., 2022). Hair et al. (2022) generally advise against pairwise deletion. They also argue that casewise deletion/listwise deletion "can dramatically diminish the number of observations in the data set" (Hair et al., 2022, p. 63). As only 177 responses remain after excluding suspicious responses and those with more than 15% missing responses, casewise deletion/listwise deletion is not a suitable option to treat missing values in this dissertation's data set. Instead, mean value replacement is used.

*Data distribution*

Lastly, before turning to the PLS-SEM model estimation, it is necessary to check the data for non-normality. This requires assessing the skewness (a measure of data symmetry) and kurtosis (a measure of tailedness) of the data. The skewness values for all indicators in the final data set are all well between -1 and 1, which is considered an excellent value (Hair et al., 2022). The kurtosis scores are all between -2 and 2, which is also considered to be an acceptable value. All but the three indicators (ROS2, CE-INV1, and CE-INV4) are even between the values of -1 and 1 (Hair et al., 2022). Hence, the data set does not show any sign of extreme non-normality, and the PLS-SEM analysis can continue.

### 3.7. Estimation of the PLS path model

After describing the data set in the previous section, the next step is estimating the PLS path model using the PLS-SEM algorithm. One of the final decisions to be made before estimating the path model is to determine the indicators' weights, as PLS allows for an individual weighting of each indicator. Also, the overall weighting scheme needs to be determined. As suggested by Hair et al. (2022), the path weighting scheme was chosen for the PLS-SEM algorithm. Furthermore, each indicator was weighted equally with a value of 1.00.

Figure 18 presents the results of the initial path model estimation. The path coefficients have standardized values in the range of -1 to +1, indicating negative or positive relationships, respectively. Values close to -1 represent strongly negative relationships, and vice versa, those close to +1 strongly positive relationships. Those close to zero represent weak and typically not statistically significant relationships. A coefficient's significance is determined through a bootstrapping procedure (Hair et al., 2022, p. 192).

Figure 18 shows that both ICA (0.455) and BAC (0.402) have a positive and significant relationship to CEI. Furthermore, the relationship of both CEI (0.489) and ICA (0.401) to PER is positive and significant. BAC does not appear to have an effect on PER (0.012), and the direct relationship is not significant. At the same time, BAC, ICA and CEI together explain 71% of the variance in PER, which can be seen from the $R^2$ value of the PER construct. Similarly, BAC and ICA jointly explain 63.9% of the variance in CEI.

The results are discussed in detail in the upcoming chapters. Section 3.8 assesses and evaluates the reflective and formative measurement models in more detail. Section 3.9 does the same for the structural model to test the research hypotheses and derive concrete recommendations.

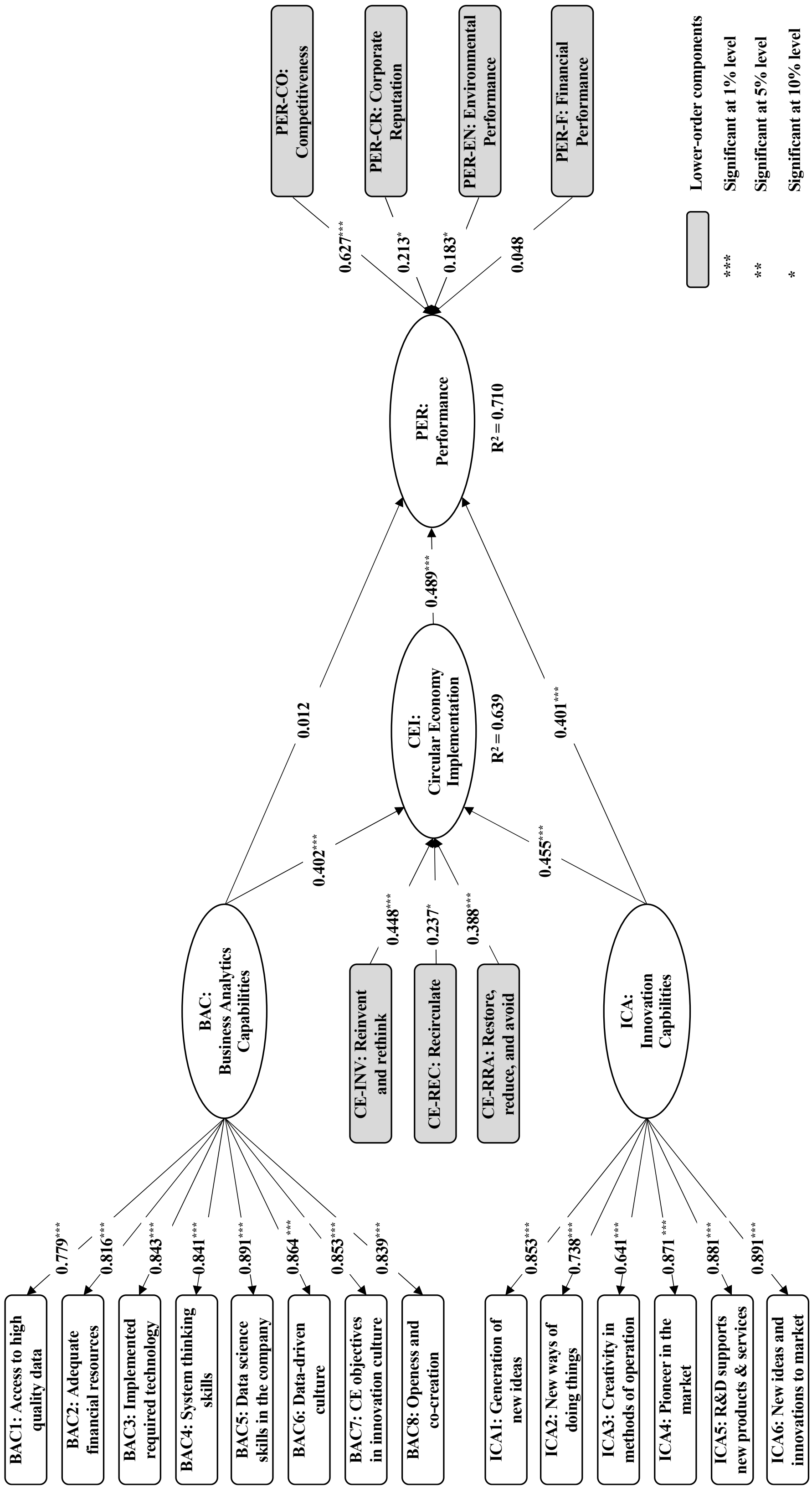



**Figure 18: Graphical results of the structural model**[22]

[22] Source: Author's illustration of the PLS-SEM results

## 3.8. Assessment of the measurement models

### 3.8.1. Assessment of the reflective measurement models

To estimate the reflective measurement models of the two exogenous constructs BAC and ICA, one needs to assess the indicator reliability, internal consistency (composite reliability), convergent validity (through the average variance extracted (AVE)), and discriminant validity (through the heterotrait-monotrait ratio of correlations (HTMT)) (Hair et al., 2022).

*Indicator reliability:* Indicator reliability measures "how much of each indicator's variance is explained by its construct" (Hair et al., 2021, p. 77). When considering indicator reliability in reflective measurement models, "a common rule of thumb is the standardized outer loadings should be 0.708 or higher" (Hair et al., 2022, p. 177), as this means that the construct explains more than 50% of the variance in the indicator (Hair et al., 2021).

The results from the PLS algorithm show that all indicators of the BAC construct are clearly above this value. BAC1 has the smallest outer loading of 0.779, which is still significantly above this threshold (Figure 18/Table 10). Regarding the ICA construct, five of the six indicators are also above the threshold of 0.708. Only ICA3 is below this value (0.641). Indicators such as ICA3, which do not meet the threshold of 0.708, "should be considered for removal only when deleting the indicator leads to an increase in the internal consistency reliability or convergent validity (…) above the suggested threshold value (Hair et al., 2022, p. 177). This is not the case for ICA3, as removing it does not increase either value. Therefore, it was decided to retain the indicator ICA3 in the final model.

**Table 10: Outer loadings of the reflectively measured constructs BAC and ICA**

| | BAC | ICA |
|---|---|---|
| **BAC1** | 0,779 | |
| **BAC2** | 0,816 | |
| **BAC3** | 0,843 | |
| **BAC4** | 0,841 | |
| **BAC5** | 0,891 | |
| **BAC6** | 0,864 | |
| **BAC7** | 0,853 | |
| **BAC8** | 0,839 | |
| **ICA1** | | 0,853 |
| **ICA2** | | 0,738 |
| **ICA3** | | 0,641 |
| **ICA4** | | 0,871 |
| **ICA5** | | 0,881 |
| **ICA6** | | 0,891 |

*Internal consistency reliability:* Internal consistency reliability refers to "the extent to which indicators measuring the same construct are associated with each other" (Hair et al., 2021, p. 77). To meet the criteria for internal consistency reliability, values for Cronbach's alpha, rho_A, and composite reliability should exceed the threshold of >0.70 (Hair et al., 2022). Concerning the path model assessed in this study, all three values are clearly above that threshold for both BAC and ICA (Table 11).

**Table 11: Overview of the internal consistency reliability measurements of the reflectively measured constructs BAC and ICA**

| | Cronbach's Alpha | rho_A | Composite Reliability | Average Variance Extracted (AVE) |
|---|---|---|---|---|
| **BAC** | 0.941 | 0.944 | 0.951 | 0.708 |
| **ICA** | 0.899 | 0.916 | 0.923 | 0.669 |

Hair et al. (2022) further note that values above 0.95 or even 0.90 are not necessarily desirable, as they tend to indicate redundant items, rephrasing the same question. This is the case for both BAC and ICA in this model, as they exceed 0.90. However, the questions to measure the BAC and ICA items are, in fact, very different from one another and do not rephrase each other (Table 1 and Table 2). None of the items can, therefore, be considered redundant, especially as the measurement models, previously tested in multiple other studies, can be considered established. Therefore, it was decided to retain all items for BAC and ICA to capture the essence of both constructs fully.

*Convergent validity assessment:* The convergent validity assessment determines the "extent to which the construct converges in order to explain the variance of its indicators" (Hair et al., 2021, p. 78). It is performed using the average variance extracted (AVE) values. The AVE value should typically be >0.50 (Hair et al., 2022). "An AVE value of 0.50 or higher indicates that, on average, the construct explains more than half of the variance of its indicators" (Hair et al., 2022, p. 120). As for this study, the AVE values for BAC (0.708) and ICA (0.669) clearly exceed the threshold (Table 11). It can, therefore, be stated that the measures of both constructs have high levels of convergent validity.

*Discriminant validity:* "Discriminant validity is the extent to which a construct is truly distinct from other constructs by empirical standards" (Hair et al., 2022, p. 120). The heterotrait-monotrait ratio (HTMT) is usually examined when assessing discriminant validity in a reflective measurement model. A maximum HTMT value of 0.85 is commonly considered conservative, whereas a value of 0.90 can be acceptable in case of very similar constructs (Hair et al., 2022). The values obtained for BAC and ICA show an HTMT value of 0.784, which is even below the more conservative threshold value of 0.85 (Table 12).

**Table 12: Heterotrait-monotrait ratio (HTMT) for the reflective constructs BAC and ICA**

| | BAC | ICA |
|---|---|---|
| **BAC** | | |
| **ICA** | 0.784 | |

In addition to evaluating the HTMT value obtained from running the PLS algorithm, the evaluation of the measurement model requires testing whether the HTMT value is significantly different from the threshold values (Hair et al., 2022). This requires conducting a bootstrapping operation in the model. The results presented in Table 13 show a value of 0.846 for the upper bound of the 90% two-sided confidence interval. This means there is a 95% probability that the HTMT value is below 0.846. As this upper bound value of 0.846 is below the threshold of 0.85, it confirms the statistical significance and, therefore, the discriminant validity of the two constructs ICA and BAC. The constructs are truly distinct from one another.

**Table 13: Heterotrait-Monotrait Ratio (HTMT) confidence interval for the reflectively measured constructs BAC and ICA**

| | Original sample (O) | Sample mean (M) | 5.0% | 95.0% |
|---|---|---|---|---|
| **ICA <-> BAC** | 0.784 | 0.783 | 0.713 | 0.846 |

Table 14 summarizes the relevant results of the evaluation of the reflective measurement model for the two exogenous constructs BAC and ICA. Both constructs meet the most relevant thresholds as described above, indicating that the measures for the two constructs have both high validity and reliability. Among all results, only the internal consistency reliability measures for BAC near the upper boundary of the desired values (Hair et al., 2022). Future research could endeavor to address this in the design of its measurement models.

**Table 14: Summary of results of the reflective measurement model**

| | | **Convergent Validity** | | | **Internal Consistency Reliability** | | | **Discriminant Validity** |
|---|---|---|---|---|---|---|---|---|
| | | Loadings | Indicator Reliability | AVE | Cronbach's Alpha | Reliability | Composite Reliability | HTMT |
| **Latent Variable** | **Indicators** | >0.70 | >0.50 | >0.50 | 0.60-0.90 | 0.60-0.90 | 0.60-0.90 | Significantly lower than 0.85 (0.90)? |
| BAC | BAC1 | 0,779 | 0,607 | 0.708 | 0.941 | 0.944 | 0.951 | Yes |
| | BAC2 | 0,816 | 0,666 | | | | | |
| | BAC3 | 0,843 | 0,711 | | | | | |
| | BAC4 | 0,841 | 0,707 | | | | | |
| | BAC5 | 0,891 | 0,794 | | | | | |
| | BAC6 | 0,864 | 0,746 | | | | | |
| | BAC7 | 0,853 | 0,728 | | | | | |
| | BAC8 | 0,839 | 0,704 | | | | | |
| ICA | ICA1 | 0.853 | 0.728 | 0.669 | 0.899 | 0.916 | 0.923 | Yes |
| | ICA2 | 0.739 | 0.546 | | | | | |
| | ICA3 | 0.643 | 0.413 | | | | | |
| | ICA4 | 0.871 | 0.759 | | | | | |
| | ICA5 | 0.880 | 0.774 | | | | | |
| | ICA6 | 0.891 | 0.794 | | | | | |

### 3.8.2. Assessment of the formative measurement models

#### *3.8.2.1. Assessment of the lower-order constructs in the formative measurement model*

As described in sections 3.4.3 and 3.4.4, the measurement models of the two endogenous constructs CEI and PER were adapted from Kristoffersen et al. (2021a), who measured them as higher-order formative constructs. As the measurement models are made up of LOCs and HOCs, this section focuses on the evaluation of the measurement models of the lower-order formative constructs CE-INV, CE-RRA, CE-REC, as well as PER-EN, PER-F, PER-CO, and PER-CR. The following section 3.8.2.2 focuses on the evaluation of the measurement models of the higher-order formative constructs CEI and PER.

*Convergent validity assessment:* According to Hair et al. (2022), the first step of the formative measurement model assessment should be to assess convergent validity, which determines "the extent to which a measure correlates positively with other (e.g., reflective) measures of the same construct using different indicators" (Hair et al., 2022, p. 143). This assessment requires that global items summarizing the respective constructs are included in the survey during the data collection phase. In this case, the survey did not include such global items for CEI or PER, as it was unknown to the author at the step of data collection that they would later be needed to assess convergent validity in the PLS-SEM model. Therefore, a convergent validity assessment is not possible, and the evaluation of the formative measurement model must continue with step two of the process (Figure 12).

*Collinearity assessment:* As is the case for the assessment of the PER construct (section 3.4.4), evaluating the formative measurement model also requires assessing the VIF values to determine whether any of the indicators are too closely correlated (Hair et al., 2022). However, none of the indicators of the formatively measured lower-order constructs reach a critical collinearity level of >5.0. As

Table 15 shows, all VIF values for the indicators are well below the threshold of 5.0, and with the exceptions of CE-REC2, even below 3.0. The indicators are, therefore, not too closely correlated with each other.

*Significance and relevance testing:* The next step in testing the formative measurement model is to assess the significance and relevance of the indicators' outer weights. Similar to the assessment of the reflective indicators, this is done with a bootstrapping procedure (Hair et al., 2022). The bootstrapping is conducted using 10.000 bootstrap samples, choosing the percentile bootstrap option, a 0.05 significance level, and the two-tailed approach.

The results show that, except for CE-INV1, CE-INV3, CE-INV4, CE-REC1, PER-EN1, and PER-F2, all other formative indicators are significant at the 5% level (Table 15). However, "nonsignificant indicator weights should not automatically be interpreted as indicative of poor measurement model quality. Rather, researchers should consider a formative indicator's absolute contribution to its constructs. (…) The absolute contribution is measured by the formative indicator's outer loading. (…) When an indicator's outer weight is nonsignificant, but its outer loading is high (i.e., above 0.50, the indicator should be interpreted as absolutely important, but not as relatively important" (Hair et al., 2022, p. 151).

As can be seen in Table 15, the outer loadings for all nonsignificant, formative indicators are well above the threshold of 0.5, with PER-F2 being the smallest (0.583) (Hair et al., 2022). Thus, all nonsignificant formative indicators are retained in the measurement model. This decision is further supported by their theoretical importance in measuring the formative constructs (i.e., their contribution to capturing the construct's meaning).

**Table 15: Overview of the evaluation criteria of the formatively measured lower-order constructs CE-INV, CE-RRA, CE-REC and PER-EN, PER-F, PER-CO, PER-CR**

| Formative Constructs | Formative Indicators | VIF | Outer Weights (Outer Loadings) | t-value | p-value | 95% Percentile Confidence Interval | Significance ($p < 0.05$)? | Outer loading |
|---|---|---|---|---|---|---|---|---|
| CE-INV | CE-INV1 | 2.050 | 0.024 | 0.201 | 0.841 | (-0.216, 0.255) | No | 0.642 |
| | CE-INV2 | 1.350 | 0.536 | 5.788 | 0.000 | (0.333, 0.692) | Yes | |
| | CE-INV3 | 2.334 | 0.188 | 1.376 | 0.169 | (-0.064, 0.464) | No | 0.711 |
| | CE-INV4 | 2.493 | 0.204 | 1.674 | 0.094 | (-0.047, 0.428) | No | 0.730 |
| | CE-INV5 | 1.929 | 0.311 | 3.113 | 0.002 | (0.120, 0.513) | Yes | |
| CE-RRA | CE-RRA1 | 1.880 | 0.295 | 3.135 | 0.002 | (0.107, 0.482) | Yes | |
| | CE-RRA2 | 2.751 | 0.248 | 2.467 | 0.014 | (0.057, 0.452) | Yes | |
| | CE-RRA3 | 2.728 | 0.568 | 5.610 | 0.000 | (0.351, 0.746) | Yes | |
| CE-REC | CE-REC1 | 2.436 | 0.166 | 1.265 | 0.206 | (-0.089, 0.419) | No | 0.824 |
| | CE-REC2 | 3.103 | 0.548 | 4.246 | 0.000 | (0.282, 0.789) | Yes | |
| | CE-REC3 | 2.169 | 0.386 | 3.703 | 0.000 | (0.170, 0.579) | Yes | |
| PER-EN | PER-EN1 | 1.826 | 0.205 | 1.886 | 0.059 | (0.003, 0.427) | No | 0.775 |
| | PER-EN2 | 2.205 | 0.452 | 4.417 | 0.000 | (0.246, 0.651) | Yes | |
| | PER-EN3 | 2.436 | 0.466 | 4.211 | 0.000 | (0.240, 0.672) | Yes | |
| PER-F | PER-F1 | 1.368 | 0.675 | 9.084 | 0.000 | (0.513, 0.805) | Yes | |
| | PER-F2 | 1.753 | 0.007 | 0.092 | 0.927 | (-0.143, 0.161) | No | 0.581 |
| | PER-F3 | 1.984 | 0.465 | 5.661 | 0.000 | (0.308, 0.629) | Yes | |
| PER-CO | PER-CO1 | 2.279 | 0.375 | 6.031 | 0.000 | (0.242, 0.489) | Yes | |
| | PER-CO2 | 2.965 | 0.310 | 4.216 | 0.000 | (0.154, 0.445) | Yes | |
| | PER-CO3 | 2.747 | 0.420 | 5.076 | 0.000 | (0.274, 0.594) | Yes | |
| PER-CR | PER-CR1 | 1.842 | 0.234 | 2.746 | 0.006 | (0.055, 0.386) | Yes | |
| | PER-CR2 | 1.946 | 0.310 | 3.227 | 0.001 | (0.124, 0.502) | Yes | |
| | PER-CR3 | 2.114 | 0.303 | 3.612 | 0.000 | (0.139, 0.468) | Yes | |
| | PER-CR4 | 2.113 | 0.344 | 4.674 | 0.000 | (0.194, 0.481) | Yes | |

#### *3.8.2.2. Assessment of the second-order constructs in the formative measurement model*

As explained above, the two proposed constructs to measure Circular Economy implementation (CEI) and firm performance (PER) are designed as higher-order formative constructs. The use of higher-order constructs requires applying the repeated indicator approach (Becker et al., 2012). In practice, this means "if a second-order latent variable consists of three underlying first-order latent variables, each with four manifest variables, the second-order latent variables can be specified using all (twelve) manifest variables of the underlying first-order latent variables" (Becker et al., 2012, p. 365). This also means "if the repeated indicator approach is used, (…) the weights and loadings are now represented by the path coefficients between higher-order (HOC) and lower-order constructs (LOC), and not by the manifest indicators that are repeated at the construct level" (Becker et al., 2012, p. 378). To assess these kinds of second-order constructs in a formative measurement model, it is necessary to test for collinearity (VIF) and the significance and relevance of the respective LOCs (Becker et al., 2012).

*Convergent validity assessment:* As previously mentioned in section 3.8.2.1, a convergent validity assessment is not possible with the data set of this study, as no global items are included in the questionnaire for CEI and PER. Therefore, the assessment of the formative measurement model begins with the collinearity assessment.

*Collinearity assessment:* The assessment of the collinearity scores shows that none of the LOCs exhibit VIF scores higher than 5.0 (Table 16). In other words, they do not show critical levels of collinearity (Hair et al., 2022). Merely, PER-CO exhibits a score close to 5.0 (4.878), which is to be expected as it has already shown a high VIF score during the separate assessment of the PER measurement model in sections 3.4.4.1 and 3.4.4.2. Nonetheless, the score remains below 5.0, which allows the structural model to continue with the two measurement models for CEI and PER.

*Significance and relevance testing:* With regards to the significance and relevance of the LOCs for the HOCs, all three LOCs of CEI are highly significant, as they exhibit p-values clearly below 0.05 (Table 16). For PER, only three of the four LOCs are statistically significant, namely competitiveness (PER-CO), corporate reputation (PER-CR), and environmental performance (PER-EN). Financial performance (PER-F) is not statistically significant (p-value = 0.649). However, its outer loading value of 0.841 is clearly above the threshold of 0.5, providing a clear argument to retain PER-F in the model (Hair et al., 2022). Similarly, the separate assessment of the PER measurement model in sections 3.4.4.1 and 3.4.4.2 supports the argument to retain all four dimensions of performance in the model, as all four LOCs are significant in that assessment. Therefore, it is ultimately decided to retain all four LOCs as part of the PER measurement model.

**Table 16: Overview of the evaluation criteria of the formatively measured higher-order constructs CEI and PER**

| Formative Constructs | Formative Indicators | VIF | Outer Weights (Outer Loadings) | t-value | p-value | 95% Percentile Confidence Interval | Significance ($p < 0.05$)? | Outer loading |
|---|---|---|---|---|---|---|---|---|
| CEI | CEI-INV | 2.448 | 0.468 | 5.611 | 0.000 | (0.303, 0.630) | Yes | |
| | CE-REC | 3.061 | 0.237 | 2.479 | 0.013 | (0.054, 0.427) | Yes | |
| | CE-RRA | 3.360 | 0.388 | 3.857 | 0.000 | (0.185, 0.584) | Yes | |
| PER | PER-CO | 4.878 | 0.627 | 4.760 | 0.000 | (0.368, 0.887) | Yes | |
| | PER-CR | 3.634 | 0.213 | 2.225 | 0.026 | (0.015, 0.390) | Yes | |
| | PER-EN | 2.557 | 0.183 | 1.987 | 0.047 | (0.004, 0.366) | Yes | |
| | PER-F | 3.225 | 0.048 | 0.455 | 0.649 | (-0.165, 0.247) | No | 0.841 |

## 3.9. Assessment of the structural model

The assessment of the reflective and formative measurement models has shown that they meet the necessary quality criteria defined in the PLS-SEM literature. This section evaluates the quality of the structural model, which is considered the central component of the PLS-SEM analysis.

*Collinearity assessment:* Similar to the assessment of formative measurement models, the structural model assessment also requires a collinearity assessment to identify any collinearity issues between constructs. The inner VIF values of the structural model are all below the threshold value of 5.0 and even below 3.0 (Table 19). This means that no critical levels of collinearity are reached.

*Explanatory power:* Assessing the model's explanatory power is typically done using the $R^2$ values of the endogenous variables. The $R^2$ value describes the share of the variance of an endogenous construct that can be explained by the related exogenous constructs (Schloderer et al., 2009). Therefore, it is one, if not the most important, value to assess in the model, as it shows how much of the variance of the endogenous constructs CEI and PER is explained by the model. It is not trivial to say which $R^2$ values can be considered as 'good' and which as 'bad'. A frequently cited example by Chin (1998) considers $R^2$ values of 0.67 as 'substantial', 0.33 as 'moderate'. and 0.19 as 'weak'. Other guidelines argue that "values of 0.75, 0.50 and 0.25 can be considered substantial, moderate and weak" (Hair et al., 2019). However, it needs to be noted that a universally 'good' $R^2$ value does not exist, as "the $R^2$ should always be interpreted in relation to the context of the study, based on $R^2$ values from related studies" (Hair et al., 2022, p. 195).

In the structural model under consideration, the $R^2$ value for CEI is 0.639, and for PER, it is 0.710 (Table 17). With regards to the guidelines by Hair et al. (2019) and Chin (1998), these $R^2$ values can be considered to be moderate in the case of CEI and between moderate and substantial in the case of PER, depending on which guideline is applied. However, both values are higher than those observed by Kristoffersen et al. (2021a), who obtained a $R^2$ value of 0.593 for the CEI construct and 0.522 for the PER construct. They are also higher than the $R^2$ values obtained by Khan et al. (2020), who observed an $R^2$ value of only 0.180 for CE and one of 0.409 for PER. Therefore, the $R^2$ values of this dissertation's structural model for CEI (0.639) and PER (0.710) are substantially above those obtained in comparable studies focusing on CE implementation and firm performance, which can be considered a satisfactory result.

**Table 17: Overview of the structural model's $R^2$ values**

| | Original sample (O) | Sample mean (M) | Standard deviation (STDEV) | T statistics (\|O/STDEV\|) | P values |
|---|---|---|---|---|---|
| **CEI** | 0.639 | 0.649 | 0.053 | 12.039 | 0.000 |
| **PER** | 0.710 | 0.722 | 0.043 | 16.616 | 0.000 |

*Predictive power:* After determining that the model has comparatively high explanatory power in the previous section, the next step in the PLS-SEM analysis is to determine the model's predictive power, which refers to the model's ability to predict new cases not included in the sample. Recent research proposes $PLS_{predict}$ to assess the predictive power of the structural model (Shmueli et al., 2019).

The $PLS_{predict}$ results show that all endogenous constructs' indicators have $Q^2$ values > 0, suggesting they outperform the most naïve benchmark (Table 18). Except for the LOC of PER-CR (corporate reputation), all other root mean square error (RMSE) values from the PLS analysis are less than the RMSE values of the linear regression model (LM). PER-CR misses this threshold by a mere 0.002. However, according to the definition by Hair et al. (2022), the model can only be considered to have high predictive power if all indicators in the PLS analysis meet the requirement of having lower RMSE values than the naïve LM benchmark. As PER-CR falls just short of meeting this criterion, it must be noted that this structural model has moderate predictive power, albeit with only a slight difference in RMSE values.

**Table 18: PLSpredict Results Report**

| | **Q²predict** | **PLS-SEM_RMSE** | **LM_RMSE** | **PLS-SEM_RMSE vs. LM_RMSE** |
|---|---|---|---|---|
| LV scores - CE-INV | 0.554 | 0.673 | 0.705 | 0.032 |
| LV scores - CE-REC | 0.457 | 0.742 | 0.796 | 0.054 |
| LV scores - CE-RRA | 0.514 | 0.701 | 0.725 | 0.024 |
| LV scores - PER-CO | 0.581 | 0.651 | 0.66 | 0.009 |
| LV scores - PER-CR | 0.479 | 0.726 | 0.724 | -0.002 |
| LV scores - PER-EN | 0.441 | 0.752 | 0.804 | 0.052 |
| LV scores - PER-F | 0.446 | 0.749 | 0.792 | 0.043 |

*Significance and relevance of path coefficients:* Concerning the significance and relevance of the structural model relationships, Table 19 gives an overview of the results of the PLS analysis. As is the case for the assessment of the measurement models, a bootstrapping procedure needs to be conducted to confirm the significance of the path coefficients between the constructs obtained during the PLS analysis (Figure 18).

The evaluation of the path coefficients finds both ICA (p-value = 0.000) and BAC (p-value = 0.000) to be highly significant in influencing CE implementation (CEI). This confirms H1 and H2. Also, the direct relationship between ICA and firm performance (PER) is found to be highly significant (p-value = 0.000). Therefore, H5 is also supported. At first glance, BAC does not appear to have a significant direct relationship to PER (p-value = 0.872). However, an evaluation of the total effects shows that the total effect of BAC on PER is indeed significant (p-value = 0.012) (Table 20). This means that CEI mediates the effect of BAC on PER, a finding that confirms previous research (Kristoffersen et al., 2021a). Most importantly, however, with regard to this dissertation's research question, the relationship between CEI and PER is highly significant (p-value = 0.000). In other words, H3, which states that CE implementation positively influences perceived firm performance, is supported.

**Table 19: Results of the evaluation of the structural model**

| Endogenous construct | Exogenous construct | VIF | Path coefficients | t-values | p-values | 95% Confidence intervals | Significance ($p < 0.05$)? | $Q^2$ (>0) |
|---|---|---|---|---|---|---|---|---|
| **CEI** | **BAC -> CEI** | 2.200 | 0.402 | 4.324 | 0.000 | (0.227, 0.589) | Yes | 0.617 |
| | **ICA -> CEI** | 2.200 | 0.455 | 4.760 | 0.000 | (0.258, 0.632) | Yes | |
| **PER** | **CEI -> PER** | 2.768 | 0.489 | 5.648 | 0.000 | (0.338, 0.671) | Yes | 0.603 |
| | **BAC -> PER** | 2.647 | 0.012 | 0.161 | 0.872 | (-0.133, 0.169) | No | |
| | **ICA -> PER** | 2.774 | 0.401 | 4.061 | 0.000 | (0.188, 0.572) | Yes | |

Once the significance has been established, the focus of the analysis shifts to the strength of the influence that the various exogenous constructs have on the endogenous constructs CEI and PER. In other words, what drives perceived CE implementation and perceived firm performance? The total effects (Table 20) show that both ICA (0.455) and BAC (0.402) have a similarly high effect on CE implementation, with ICA's effect being slightly higher. Thus, both innovation capabilities and business analytics capabilities support firms in the construction and manufacturing industries in implementing CE initiatives.

Regarding the total effect on PER, ICA (0.623) appears to have the most substantial total effect on the perceived performance of companies in the construction and manufacturing industries. However, the total effect of CEI on PER is also very high (0.489) and, interestingly, significantly higher than that of BAC (0.209). Therefore, although innovation capabilities appear to be the strongest driver of perceived performance, CE implementation and business analytics capabilities are also important drivers of perceived firm performance in the two industries examined in this study.

**Table 20: Overview of total effects in the structural model**

| Endogenous construct | Exogenous construct | Original sample (O) | Sample mean (M) | Standard deviation (STDEV) | T statistics (\|O/STDEV\|) | p-values |
|---|---|---|---|---|---|---|
| CEI | BAC -> CEI | 0.402 | 0.405 | 0.093 | 4.324 | 0.000 |
| | ICA -> CEI | 0.455 | 0.455 | 0.096 | 4.760 | 0.000 |
| PER | CEI -> PER | 0.489 | 0.504 | 0.086 | 5.648 | 0.000 |
| | BAC -> PER | 0.209 | 0.216 | 0.083 | 2.527 | 0.012 |
| | ICA -> PER | 0.623 | 0.618 | 0.079 | 7.852 | 0.000 |

In order to determine which specific aspects of the respective exogenous constructs should be addressed to improve CEI and PER, the outer weights of the exogenous constructs' indicators need to be assessed (Hair et al., 2022). In the structural model, CE-INV ('reinvent and rethink') has an outer weight of 0.468, which is greater than that of CE-RRA ('restore, reduce and avoid') (outer weight = 0.388) and that of CE-REC ('recirculate') (outer weight = 0.237) (Table 16). Going one level deeper, the measurement model assessment conducted in section 3.8.2.1 suggests that among the first-order construct CE-INV, the indicators CE-INV2 *('we support products during their lifetime through providing spare parts and/or repair services as separate sales offerings'*) and CE-INV5 (*'we design for easy disassembly'*) have the most considerable effect on the second-order construct CEI. They have outer weights of 0.536 and 0.311, respectively (Table 15). In other words, companies with limited investment resources can expect the most significant gains in CE implementation by offering spare parts/repair services on top of their regular products and by designing for easy disassembly.

Conducting the same assessment is impossible for the BAC and ICA constructs as they are measured reflectively. Therefore, they have outer loadings instead of outer weights. Additional exploratory research is needed to determine which specific business analytics and innovation capabilities are being developed on a company level and how they are used to advance CE implementation. In the case of innovation capabilities, RQ 2 of this dissertation sets out to address exactly this question. The qualitative study, described in chapter 4 of this dissertation, explores the role of innovation capabilities for CE implementation. Therefore, the findings of the quantitative studies lay the foundation for the second, qualitative study conducted in this dissertation.

## 3.10. Advanced PLS-SEM analyses

When applying PLS-SEM, several advanced analyses are possible in addition to the standard assessment of the structural model described in the previous sections. In the context of this study, a multigroup analysis is especially interesting, primarily because, as section 3.6 has shown, there are several notable sub-groups within the data set. Most notably, it comprises companies from two industries – the construction and manufacturing industries. So far, the data has been treated as a homogenous data set. A multigroup analysis tests whether the path coefficients in the structural models differ significantly statistically between the two groups (Hair et al., 2022).

Consideration was given to whether it is possible to conduct a multigroup analysis to detect statistically significant differences between the two industries. However, each of the two industries only has a small sample size. In the data set used for this study, the sample size is n = 90 for the construction industry and n = 87 for the manufacturing industry (Table 9). Literature on multigroup analyses explains that "if researchers expect only small group differences, more than 1,000 observations per group are required" (Klesel et al., 2022). Since the possibility that differences between the industries are, in fact, small cannot be ruled out, a multigroup analysis with a sample size of only about 90 observations per group cannot be conducted.

To still get some insights into the differences between the two industries, an alternative is to compute the structural model for each of the two samples separately. Such an analysis allows for a comparison of numerical differences between the path coefficients but does not allow for the testing of significance of the differences. Nevertheless, it can still deliver some insights. However, once again, sample size becomes an issue. As stated in section 3.6, the minimum sample size for this model, according to the inverse square root method, is 97 (Kock & Hadaya, 2018). The sub-samples of both industries slightly miss this value (construction industry = 90, manufacturing industry = 87). However, as the sample size for this analysis falls just 10% short of the recommended minimum, it was decided to proceed with the analysis to determine if any differences between the two industries can be observed. As the minimum sample size is not reached, it must be disclosed in advance that the results should only be understood as an indication and do not claim to provide a 100% accurate picture.

With that in mind, Table 21 summarizes the results of the PLS analysis of the construction and manufacturing sub-samples. As no multigroup analysis is possible, no statements can be made about the significance of the differences between the two industries. Nonetheless, it is interesting that there seem to be some small differences between the two industries. The analysis indicates that perceived CE implementation (CEI) might be influenced slightly differently in the two industries. While CEI in the construction industry appears to be influenced more by ICA (0.510) than BAC (0.391), the opposite appears true for the manufacturing industry. In the manufacturing industry, the path coefficient between BAC and CEI is 0.448 and slightly lower between ICA and CEI (0.398). Also, the direct relationship between ICA and PER (H5), which is significant at the 5% level in the construction industry (p-value = 0.003), is slightly above the p-value of 0.05 in the manufacturing industry (p-value = 0.053), which would mean it is not significant. Most importantly, in the context of this study, the relationships between from BAC and ICA to CEI (H1 & H2) and CEI to PER (H3) appear to be statistically significant in both industries (Table 21).

**Table 21: Comparison of PLS-SEM results for the two industry sub-samples**

| Endogenous construct | Exogenous construct | Path coefficients | | p-values | | Significance (p < 0.05)? | |
|---|---|---|---|---|---|---|---|
| | | Constr. | Manuf. | Constr. | Manuf. | Constr. | Manuf. |
| CEI | BAC -> CEI | 0.391 | 0.448 | 0.001 | 0.001 | Yes | Yes |
| | ICA -> CEI | 0.510 | 0.398 | 0.000 | 0.003 | Yes | Yes |
| PER | CEI -> PER | 0.532 | 0.540 | 0.000 | 0.000 | Yes | Yes |
| | BAC -> PER | -0.003 | 0.029 | 0.966 | 0.842 | No | No |
| | ICA -> PER | 0.383 | 0.321 | 0.003 | 0.053 | Yes | No |

Once again, given that both subsamples barely miss the suggested minimum sample size requirements, the findings, as presented in Table 21, need to be confirmed in future research.

## 3.11. Summary of the PLS-SEM analysis

The previous section focused on evaluating the results of the PLS-SEM analysis. This section summarizes the essential findings and puts the results in context with the literature to discuss the first research and managerial implications. A more detailed discussion of the findings will follow in section 5.1 of this dissertation.

The PLS-SEM analysis shows that the proposed model has a high explanatory power for CE implementation (CEI) and perceived firm performance (PER). The significance and relevance testing of the path coefficients (Table 19) indicates that research hypotheses 1-5 are all supported, and their relationships can be confirmed. In the case of H4 (*'higher levels of perceived BAC have a positive influence on perceived PER'*), the effect of business analytics capabilities (BAC) on perceived firm performance (PER) is fully mediated by CE implementation (CEI) and only the total effect is statistically significant. These results are summarized in Table 22.

**Table 22: Results of the structural model**

| Hypothesis | Hypothesized relationship | p-value | Total Effect | Result |
|---|---|---|---|---|
| H1 | Higher levels of perceived BAC have a positive influence on perceived CEI | 0.000 | 0.402 | Confirmed |
| H2 | Higher levels of perceived ICA have a positive influence on perceived CEI | 0.000 | 0.455 | Confirmed |
| H3 | Higher levels of perceived CEI have a positive influence on perceived PER | 0.000 | 0.489 | Confirmed |
| H4 | Higher levels of perceived BAC have a positive influence on perceived PER | 0.005 | 0.216 | Confirmed (fully mediated by CEI) |
| H5 | Higher levels of perceived ICA have a positive influence on perceived PER | 0.000 | 0.618 | Confirmed |

From a research perspective, this quantitative study has achieved two significant results. Firstly, it proves a positive relationship between perceived CE implementation and perceived firm performance in the construction and manufacturing industries (H3 confirmed). Therefore, it validates the previous findings by Khan et al. (2020) and Kristoffersen et al. (2021a), who observed this correlation between CEI and PER in a cross-industry data set. This study additionally proves that even in the construction and manufacturing industries, two industries that research does not consider to be very advanced in terms of CE implementation (K. T. Adams et al., 2017; Kristoffersen et al., 2020), CEI appears to have a significant, positive effect on perceived firm performance.

The second important finding from this study is that it confirmed H1 and H2. On the one hand, this means it validated the findings by Kristoffersen et al. (2021a) that BAC can be an essential driver of CEI (H1), also in the construction and manufacturing industries. On the other hand, the study has shown that the total effect of innovation capabilities (ICA) on CEI (H2) is slightly larger than the total effect of BAC (0.455 vs. 0.402) (Table 22). This is an important addition to the previous literature on CEI, as it extends previous models, such as those of Jakhar et al. (2018) or Kristoffersen et al. (2021a), and shows that innovation capabilities are just as important as business analytics capabilities, if not even more relevant. To the author's knowledge, this is the first study in the context of CE implementation that assesses both BAC and ICA simultaneously.

These findings are also highly relevant for managers in the construction and manufacturing industries. In combination, the confirmation of H1 and H2, as well as H3, shows firms that investments in both business analytics and innovation capabilities will support CE implementation and, more importantly, subsequently, even firm performance. As firms constantly seek to improve their performance and gain an edge over their competition, these findings are an essential contribution to the literature. They suggest that a transition to the CE is not only compatible with a firm's pursuit of higher performance but can even positively influence firm performance. In that context, the findings also support multiple studies that have been published over the years by governmental actors, such as the European Commission (European Commission, 2014a), or by non-governmental institutions and think tanks, such as the EMF (Ellen MacArthur Foundation, 2015b, 2016), with empirical evidence. While these studies have often advocated for the upside potential of CE implementation, argumentation, particularly in the case of the EMF, is often based on successful pilot projects of selected companies and less on large-scale quantitative studies, as conducted in this study.

### 3.12. Potential limitations of the quantitative study

A potential limitation of this study is that, as described in sections 3.4.3 and 3.4.4, both endogenous constructs, PER and CEI, have been measured with subjective rather than objective indicators. In recognition of this fact, the terms *'perceived'* CE implementation and *'perceived'* firm performance have been used throughout this study when discussing the results of the PLS-SEM analysis. The reason why both constructs were measured subjectively, through the self-assessment of the surveyed employees, was primarily the difficulty to obtain objective data, especially for the indicators of the CEI construct. Many companies either do not record data, such as the percentage of recycled materials used, or, especially in the case of SMEs, do not report this data publicly. The same applies for data on company performance, both in terms of financial performance as well as environmental performance (e.g., amount of waste generated, number of emissions caused, etc.). To avoid having to focus on a very limited set of companies that do record and publish this data, it was decided to use subjective measurement models for CEI and PER, respectively. Further details and reasoning for this decision are provided in sections 3.4.3 and 3.4.4. Nevertheless, it can certainly be argued that this choice of subjective measurements presents a limitation. Therefore, it might be an exciting opportunity for future studies to measure CE implementation objectively based on company-reported data and to test its impact on objectively measured performance constructs. However, research in this area should always bear in mind that measuring performance with purely financial indicators (e.g., ROI) does not do justice to the complexity of the firm performance construct (Richard et al., 2009).

# 4. Qualitative study

The PLS analysis in the previous chapter of this paper produces two major results. First, it proves that there is indeed a positive relationship between perceived CE implementation and perceived firm performance in the construction and manufacturing industries. Second, it shows that innovation and business analytics capabilities can significantly help firms in these two industries improve their CE implementation.

However, a quantitative analysis cannot provide firms with concrete advice on how to concretely improve the exogenous constructs of BAC, ICA, and CEI to ultimately achieve higher firm performance. It can also not give insights into the specific business analytics and innovation capabilities that firms leading in CE implementation have developed, nor can it provide insights into the processes how firms apply these capabilities to advance CE implementation. From a research- and, of course, also from a managerial perspective, these would be incredibly interesting findings. Therefore, for this dissertation, it was decided to follow up on the results of the PLS analysis with a qualitative study aimed at generating exactly these insights.

However, while both exogenous constructs (BAC and ICA) show significance in the PLS model, the qualitative study focuses on only one of the two constructs. Given that the innovation capabilities construct (ICA) showed higher total effects for both CEI and PER (Table 20), the qualitative study focuses on the relationship between innovation capabilities and CE implementation. This does not indicate that the relationship between BAC and CEI is less important but is simply due to the scope of this dissertation.

Literature on innovation in the context of the CE also calls for more detailed exploratory research in this area. A recent literature review on innovation and the CE states that "detailed in-depth analyses of [Eco-Innovation] practices and dynamics are still largely absent in the corpus of the CE literature" (de Jesus et al., 2021, p. 15) criticizing that "innovation is presented (…) as a broad concept, without specific references to how innovation is conceptualised [sic], what the key processes and who the stakeholders driving innovation are, or even the direction and objectives of the innovation processes in a CE" (de Jesus et al., 2021, p. 15). Similarly, Sehnem et al. (2021) observe in their systematic literature review, that there are "opportunities to investigate the CE and innovation from an applied, managerial and strategic perspective for organizations" (Sehnem et al., 2021, p. 241). Furthermore, they conclude that among existing literature “little emphasis was placed on mechanisms for implementing innovation in circular contexts and types of innovation relevant to the CE” (Sehnem et al., 2021, p. 241). These observations are in line with the findings of the more detailed literature review presented in section 2.3 of this dissertation. Therefore, both the findings of the quantitative study and existing literature provide reasons to examine the relationship between innovation and the CE more closely.

Naturally, this needs to be researched among firms that have already implemented circular innovations, as they are the only ones who can provide insights on how innovation capabilities affect CE implementation in practice. For the qualitative study, the overall research question is therefore:

*RQ 2: How can firms in the construction and manufacturing industries leverage innovation for the implementation of the Circular Economy in practice?*

As this research question remains relatively broad, it was decided to split RQ 2 into three sub-research questions. The sub-research questions consider the need to provide additional insights regarding the types of innovation relevant to the CE (RQ 2.1 & RQ 2.2) (Sehnem et al., 2021), as well as the findings of this dissertation’s quantitative study, which highlight the need to explore the role of innovation capabilities in helping firms to implement the CE (RQ 2.3). The three sub-research questions to RQ 2 are therefore:

*RQ 2.1: Which kind of circular innovations have been pursued by CE frontrunner firms in the construction and manufacturing industry?*

*RQ 2.2: How can firms in these industries effectively decide which circular innovations to pursue?*

*RQ 2.3: Which innovation capabilities can assist firms in implementing circular innovations?*

### 4.1. Research design

Before delving into the methodology, it is important to note that this qualitative study examines the construction and manufacturing industries from a slightly different angle. In the quantitative study (chapter 3), respondents were asked to self-identify their industry, and their responses were counted if they selected that they worked either in construction[23] or manufacturing. This qualitative study focuses solely on producers within both industries. Therefore, the angle on the construction industry is narrower than in the quantitative study, as no companies or actors involved with the delivery of services are included. This was done to ensure better compatibility with the manufacturing sector, which also solely includes producing companies.

Sampling was done as follows: A first criterion for selecting firms for the interviews was naturally their industry affiliation with either the construction or the manufacturing industry. Furthermore, only those firms were approached for interviews that have already implemented significant CE initiatives and could thus be considered frontrunners in terms of CE implementation within their industry. One of the criteria used to identify suitable companies was whether they had achieved C2C certification for one or multiple of their products, given the high standards required in the product circularity dimension of the C2C certification assessment. However, this approach alone did not yield sufficient potential companies. This is due to two reasons. Firstly, the C2C certification costs several thousand Euros and, even more importantly for many start-ups and SMEs, ties up significant resources to carry out the complex certification process (cradle to cradle products innovation institute, 2023). Therefore, some SMEs do not prioritize official C2C certification, even though their products meet many of the criteria. Secondly, few products, especially in the manufacturing sector, have been C2C certified to date. Any exploration into circular innovation in the manufacturing industry must consequently also include producers of other, non-C2C certified products that fulfill circularity criteria.

Therefore, in addition to those companies that offer C2C-certified products, other companies were also contacted that have already implemented significant circular strategies and thus justify the designation CE frontrunner. Examples of circular strategies include the large-scale use of recycled or biodegradable materials or the introduction of circular business models, such as reconditioning, remanufacturing, and product-as-a-service models (PaaS). Table 23 provides

[23] Defined as: Construction of buildings of all kinds, including "new work, repair, additions and alterations, the erection of pre-fabricated buildings or structures on the site and also construction of temporary nature. Included is the construction of entire dwellings, office buildings, stores and other public and utility buildings, farm buildings, etc." (Eurostat, 2008, p. 209).

an overview of the companies included in the final sample, and a brief description of the circularity criteria that led to their inclusion.

**Table 23: Overview of company sample in the qualitative study**

| Company No. | Industry | Selection criteria as CE frontrunner | C2C certified | Interviewees No. |
|---|---|---|---|---|
| 1 | Construction | Products designed for reuse and made exclusively from biodegradable materials, following the C2C concept. | No | 1 |
| 2 | Construction | Use of recycled and biodegradable materials in new products. Products designed for recycling. | No | 2 |
| 3 | Manufacturing | Introduction of refurbishment, remanufacturing, and repair as additional business models. Products designed for refurbishment, remanufacturing, and recycling. Products are C2C certified. | Yes | 3, 13, 14 |
| 4 | Construction | Products designed for reuse and recycling and are made with recycled materials. | No | 4 |
| 5 | Construction | Introduction of C2C certified product line. | Yes | 5 |
| 6 | Construction | Introduction of C2C certified product line. | Yes | 6, 7, 8 |
| 7 | Manufacturing | Introduction of product-as-a-service business model. Expansion into recycling as additional business model. Use of recycled materials in new products. | No | 9, 12, 16 |
| 8 | Manufacturing | Introduction of rental business model in combination with refurbishment, remanufacturing, and repair. Introduction of product take back in combination with establishment of own recycling facilities. | No | 10, 20, 21 |
| 9 | Manufacturing | Introduction of product-as-a-service business model and reuse business model. Expansion into recycling as additional business model. Use of recycled materials in new products. | No | 11 |
| 10 | Construction | Expansion into recycling as additional business model and offering of product take back system. Use of >50% recycled materials in new products. | No | 15 |
| 11 | Construction | Use of recycled materials in new products. Material reduction of >75% for selected products. Expansion into recycling as additional business model. | No | 17, 18 |
| 12 | Manufacturing | Introduction of refurbishment as additional business model. Products increasingly designed for recycling and made with recycled materials. | No | 19 |

Managers within these companies' innovation or CE/sustainability departments were contacted as potential interviewees. In some cases, depending on the firm's size, even the managing directors were interviewed. Particularly in the case of SMEs, they often had the most information about CE implementation within the firms. In other cases, the initial contacts redirected the interview request to colleagues with the required CE expertise (e.g., those who had worked on the C2C certification). Initial contact with the companies was established either via E-Mail or via LinkedIn.

Given the exploratory nature of the research, semi-structured interviews were conducted to gather the interviewees' answers, as they allowed for probing, open-ended questions and the opportunity to follow up on leads and issues discovered throughout the interview (W. C. Adams, 2015). The questionnaire contained twelve questions, with several potential follow-up questions to each of these questions (see Appendix B for more details).

In most cases (14), the interviews were conducted via videoconference. Two interviews were conducted via phone, and one interview was conducted on site. They lasted between 27 and 64 minutes[24]. The majority of interviews were recorded and later transcribed. In a few cases, interviewees preferred for notes to be taken and did not wish to be recorded. Table 24 provides an overview of the interviews conducted as part of the qualitative survey.

**Table 24: Overview of the interviews conducted for the qualitative study**

| Interviewee No. | Industry | Position | Format | Duration | ID |
|---|---|---|---|---|---|
| 1 | Construction | Head of Public Relations | Videoconference | 39 min. | Con1 |
| 2 | Construction | Head of Sustainability | Videoconference | 56 min. | Con2 |
| 3 | Manufacturing | Manager Process Management and Key Contact C2C | Videoconference | 47 min. | Man1 |
| 4 | Construction | Technical Director | Videoconference | 58 min. | Con3 |
| 5 | Construction | Sales Manager and Key Contact C2C | Videoconference | 39 min. | Con4 |
| 6-8 | Construction | 1. Head of R&D<br>2. Sustainability Management Coordinator<br>3. Engineer for Norms and Standards (C2C) | Videoconference (Group) | 50 min. | Con5, Con6, Con7 |
| 9 | Manufacturing | Manager Material Engineering | Videoconference | 39 min. | Man2 |
| 10 | Manufacturing | Head of Sustainability Management | Videoconference | 64 min. | Man3 |
| 11 | Manufacturing | Researcher Circular Economy | Videoconference | 44 min. | Man4 |
| 12 | Manufacturing | Manager Environmental Product Management | Phone | n/a[5] | Man5 |

[24] Some interviewees asked not to be recorded and instead preferred for notes to be taken. For these interviews, no duration periods are available.

| | | | | | |
|---|---|---|---|---|---|
| 3[25], 13-14 | Manufacturing | 1. Head of Production Site<br>2. Manager Process Management and Key Contact C2C<br>3. Manager Reconditioning and Key Contact C2C | In-Person (Group) | n/a[5] | Man6, Man1[6], Man7 |
| 15 | Construction | Head of Product Management and Key Contact CE | Phone | n/a[5] | Con8 |
| 16 | Manufacturing | Manager Innovation & Sustainability | Videoconference | 50 min. | Man8 |
| 17 | Construction | Head of Business Unit | Videoconference | 51 min. | Con9 |
| 18 | Construction | Head of Product Development | Videoconference | n/a[5] | Con10 |
| 19 | Manufacturing | Manager Corporate and Sustainability Strategy | Videoconference | 27 min. | Man9 |
| 20-21 | Manufacturing | 1. Manager Rental and Leasing Unit<br>2. Researcher Circular Business Models | Videoconference (Group) | n/a[5] | Man10, Man11 |

## 4.2. Methodology

In the next step, the transcribed interviews and notes were collected, coded, and analyzed in MAXQDA (VERBI Software, 2021). Inductive coding was used to do justice to the comparative novelty of the research field and to capture the true essence of the data collected. In a first coding cycle, the data was coded using initial coding (Saldaña, 2013). Following up with focused coding/axial coding (Charmaz, 2006) in a second coding cycle, codes were subsequently clustered into higher-level categories based on similarities and patterns identified during the analysis (Skjott Linneberg & Korsgaard, 2019).

This methodology was applied to answer RQ 2.1 (section 4.3.1) and RQ 2.2 (section 4.3.2). To answer RQ 2.3, the codes from the previous inductive coding were linked to the theory of innovation capabilities and clustered along the dimensions of the innovation capabilities model by Lawson and Samson (2001) (Figure 10). One might argue that this introduces aspects of deductive coding to the coding methodology. However, since the model is widely recognized in the innovation literature, and as the aim of this qualitative study is to examine the role of innovation capabilities in a CE rather than to propose new models in innovation theory, the pre-established dimensions of the innovation capabilities model were used for clustering the

[25] This interviewee was interviewed twice, once via videoconference and a second time as part of an on-site group interview.

codes. Consequently, the elements of innovation capabilities proposed by Lawson and Samson (2001) were accepted as dimensions for the coding.

## 4.3. Findings

The following section is divided into three parts to present the findings in a structured manner, each providing insights for one of the three sub-research questions (RQ 2.1, RQ 2.2, and RQ 2.3). Section 4.3.1 focuses on the different types of circular innovations found among CE frontrunners. Section 4.3.2 sheds light on the decision-making process among CE frontrunners for the implementation of circular innovations. Section 4.3.3 ultimately examines the concrete innovation capabilities found to facilitate the implementation process itself.

### 4.3.1. Circular innovation types in the construction and manufacturing industries

The first finding from the interviews is that companies in the sample report very different kinds of circular innovations. These circular innovation efforts are categorized in the following chapter. The need to differentiate between various types of circular innovations follows insights from the literature. As described in section 2.3, each innovation type identified by Schumpeter (1934) is also relevant in a CE. In the context of the CE, in particular, researchers have proposed a categorization of eight different types of innovation: "business model innovations, network innovations, organizational structure innovations, process innovations, product innovations, service innovations, market innovations and customer engagement innovations" (Prieto-Sandoval et al., 2018, p. 612).

Although all of these dimensions were also observed in this study, this dissertation focuses on product-related innovations. Despite their relevance, market or organizational structure innovations are not included in this chapter. Within the dimension of product-related innovations, product composition (material innovation) and product design (DfX innovation) are defined as two separate categories. Therefore, by adapting the framework of Prieto-Sandoval et al. (2018), this chapter describes a total of five product-related categories of circular innovation identified from the interviews: (production) process innovation, material innovation, DfX innovation, upstream circular business model innovation (CBMI), and downstream CBMI. Sections 4.3.1.1 to 4.3.1.5 will describe each category in detail and explain the context in which they are implemented, their benefits for producers in the two industries, and the effort levels associated with implementing them.

#### *4.3.1.1. (Production) process innovation*

*Description:* The first category of circular innovation identified among the sample companies concerns pre-consumer waste recycling and refers to innovation in the production processes. Interviewees within both industries mentioned they developed methods to recycle pre-consumer waste, in other words, production waste. One interviewee explained: "(…) 4% recycled content [in the products]. And these 4% are the result of the fact that we also perform pre-consumer recycling. The dust is extracted, chemically recycled, and then fed back into the production process" (Con2). Another interviewee from the automotive industry explained that "(…) there are also natural overlaps between the areas, such as production waste. One example is plastic, but also, for example, aluminum during production, for which there is a possibility to achieve CO2 reductions in the product through closed loop recycling" (Man5).

*Observed upside potential:* On the cost side, introducing recycling of pre-consumer waste can, among other things, allow companies to avoid waste treatment fees. One interviewee confirmed that the company's efforts to segregate production wastes more granularly led to an opportunity to sell the materials to interested third parties rather than having to dispose of them for a waste treatment fee (Man1). Furthermore, pre-consumer waste recycling can help firms to reduce the need for virgin raw materials. In the abovementioned example from the construction industry, the interviewee reported that 4% of total materials were substituted by recycled pre-consumer waste (Con2). These low numbers (i.e., 4%) indicate that the potential impact of production process innovation can be somewhat limited.

Still, depending on recycling costs, this innovation can help companies reduce their overall material costs and partially reduce their dependence on new raw materials. From a CE point of view, it is also positive that pre-consumer waste is recycled. However, the CE hierarchy also shows that reducing or eliminating pre-consumer waste altogether would be even more desirable (Directive 2008/98/EC, 2008).

*Effort level:* For production process innovation, innovation occurs largely independently of the product itself. Production waste is collected, sorted, and eventually treated before being re-introduced into the production process as secondary raw material. Innovation, in this case, as the name already suggests, refers to adapting processes in the production rather than adapting the product itself. The difficulty of pre-consumer recycling innovation depends on whether technologies for recycling production waste are already established. Naturally, recycling, e.g., mono-material metal scraps, is easier than recycling production waste consisting of composite materials. However, if pre-consumer production waste can be easily separated and recycling technologies are established, the effort required for this innovation category is minimal. In some cases, the collected production waste can even be used as a direct substitute for virgin raw materials, almost without undergoing any previous treatment (Con9, Man5).

Another reason why this type of circular innovation requires comparatively little effort is that the firms typically retain ownership of the materials when they collect the waste from, for example, sawing or slicing processes in production. Therefore, they do not need to involve many other stakeholders along the value chain and only need to collaborate with recyclers, and even then, only if they cannot reuse the production waste directly as an input material in production.

#### *4.3.1.2. Material innovation*

*Description:* Material innovation is the second category of circular innovation identified in the interviews. Shifting towards renewable or recycled materials for specific products has been a common CE strategy identified in companies from both industries. By replacing virgin raw materials with alternative, circular materials, firms actively reduce the consumption of virgin raw materials, thereby contributing to a CE. However, there were notable differences between the companies interviewed in the way that new materials were introduced. Some firms passed on new criteria to their suppliers, hence essentially outsourcing the initial R&D to other stakeholders further up the value chain. One interviewee from the construction industry described these conversations with suppliers: “Now that we are consciously involved in this [C2C] process, i.e., when we inquire about a new raw material, the inquiry is much, much more detailed than we might have done in the past (…) - cradle to cradle - does it fit for that, or does it not fit?” (Con4). In this example, the interviewed producer changes the product design of the end-product by changing the materials, potentially by changing suppliers, but he does not develop new circular materials himself. In contrast, other interviewed firms specifically engaged in significant R&D activities to develop new, circular materials together with suppliers, universities, or start-ups (Con1, Con3).

At this point, it needs to be noted that all firms interviewed are producers of components or end-products, so they are all positioned relatively far down the value chain. Few of them develop materials themselves. Most firms source materials from the chemical industry or other suppliers and only develop circular materials in cooperation with them, as one interviewee described: “And at that moment, we changed the process in a way that we would become way more open for everything and would bring these materials, these innovations over the line together with our suppliers” (Man2).

*Observed upside potential:* On the revenue side, interviewees, particularly in the construction industry, explained that some customers have begun explicitly demanding circular materials in recent years. Material innovation has opened revenue opportunities, which some interviewed firms could otherwise not have addressed with their product portfolio. “Without the [C2C] certification, we would simply no longer be able to build and execute some projects because the client and the architects and planners simply place an extremely high value on it. That is, to have a certain product scope certified according to Cradle to Cradle” (Con5). Another example comes from a firm in the construction industry that has spent years developing a product using circular materials: “For two years now, our telephone has been ringing non-stop, and the people are saying: ‘We cannot build with plastics anymore. We need a material that is not susceptible to moisture. We would like to have a life-long performance. We would like something that can be recycled.’ And now we only say: Yes, yes, yes, and yes” (Con3).

Innovation for circular materials can not only provide access to new revenue streams but also help firms avoid unnecessary extra costs. In many cases, e.g., the production of EV batteries, regulations simply require the use of a certain percentage of recycled materials. Not complying with such regulations would result in significant fees and, thus, unnecessary costs, negatively impacting the companies’ financial performance. An interviewee from the automotive industry explained that “(…) what is already active now is the battery, battery regulation of the EU, which actually demands quotas of recycled materials and also demands them from our own batteries. That is recyclate quotas of (…) 4% for nickel and lithium and 12% for cobalt“ (Man8).

The costs of the materials themselves are, of course, an even more important aspect on the cost side. There have been some studies in this area in recent years which show that the cost of some recycled materials can still be higher than the cost of virgin raw materials. For example, for the period from Q4 2016 to Q1 2022, prices for rPET (food grade) have been above prices for virgin PET (food grade) with only one small exception (Kahlert & Bening, 2022). However, section 2.2.2 has shown how increasing resource scarcity has led to price increases for many raw materials in the construction and manufacturing industries. For materials such as copper or other metals, which are becoming rarer and more complicated to mine, research has found a positive business case for the use of recycled materials, which have the potential to be significantly less expensive than their virgin alternatives (Zeng et al., 2022). In such cases, firms that successfully introduce circular materials can directly benefit from these cost advantages. Additionally, as explained by an interview from the manufacturing industry, companies can benefit from supply chain independence by using circular materials, thereby protecting themselves against disruptions, such as those caused by the COVID-19 pandemic or the Russian invasion of Ukraine in 2022 (Man8). Such independence from fragile supply chains for CRMs is another clear advantage of using circular materials, in addition to the financial benefits.

*Effort level:* As described above, this category of circular innovation focuses on changing the material composition through internal or external innovation. Of course, depending on whether materials are readily available on the market or need to be newly developed, the efforts associated with material innovation differ across the firms in the sample. However, changing for circular materials typically requires higher efforts than implementing pre-consumer waste recycling (section 4.3.1.1). Almost all interviewees who mentioned that their firms had introduced circular materials in their products, described tedious testing and refinement processes for CE products. This is mainly because both industries are heavily regulated and typically subject to extensive quality and safety testing. For instance, one interviewee explained that introducing new products with recycled content resulted in extensive testing and certification efforts. Products made from virgin materials do not pose any significant problems in that regard, as materials and processes are standardized. Recycled cement on the other hand, the material in this case, is much more complex (Con10).

In addition to these testing and certification efforts, one interviewee whose firm developed new components to eliminate harmful materials, such as lead, stated: "So if we rely on brass, for example, which is suddenly no longer allowed to contain lead, and I then have some turning components, then I have to start thinking about the implications of this for the production process" (Con5). Hence, changing from linear to circular materials has far-reaching consequences, including, but not limited, to testing, certification, and production processes.

#### *4.3.1.3. Design innovation for reuse, refurbishment, and recycling*

*Description:* The third category of circular innovation also falls under product innovation and relates to designing to reuse, refurbish, and recycle. By designing for reuse, refurbishment, and recycling (DfX), companies primarily ensure that materials remain in the loop for longer. Design for reuse or refurbishment means products can enter a second life cycle, reducing the need for virgin materials, as the products' EOL is prolonged. Design for recycling (DfR) means products can be easily dismantled or consist of mono-materials, facilitating material recovery at the EOL. As a result, in theory, DfX leads to fewer materials ending up as waste while simultaneously increasing the availability of recycled raw materials on the market.

One method to implement DfX in practice is for firms to innovate on the material side (i.e., substituting composite materials with mono-materials). As one interviewee from a vehicle manufacturer explained: "The first big lever is actually a higher degree of purity, more mono-material instead of … at the moment there are over 60 different steel coatings and over 30 different plastics built into the vehicle" (Man8). Another common method to ensure DfX is changing the product architecture, or, in other words, the way the products are assembled. One interviewee gave the example of switching from welding to using screws in the assembly (Man1).

*Observed upside potential:* The upside potential from DfX innovation for the CE overall is immense. In fact, DfX on a company level is one of the most crucial cornerstones if the transition to a CE is to be successful on a large scale (den Hollander et al., 2017). DfX can ensure materials are kept in cycles, and that the need for virgin materials decreases. Any product not designed for reuse, refurbishment, or recycling will ultimately end up as waste. Therefore, DfX is not a nice-to-have for the CE, but it is a prerequisite without which a CE will not be possible.

There is also significant upside potential for individual companies. Some interviewed companies stated that customers were actively enquiring about products that were designed for recycling. "(…) the ability to be recirculated is, of course, a big issue, which is more and more overseen by the regulatory side, but also demanded more and more by the customer side" (Con6). However, this dissertation argues that although the overall potential benefits of DfX for the CE are enormous, the potential benefits for producers may be limited. If the producer does not retain ownership of the products, or if they do not receive them back at the EOL, they have no direct monetary benefits from designing for reuse, refurbishment, or recyclability, as recyclers are ultimately the ones benefiting from being able to separate materials more easily.

With regards to the automotive industry, one interviewee explained: "In this respect, there is a network, a partner, with whom we work, who offers these take-back points, so to speak, and until now the deal there has always been: you accept the vehicles for us (…) and you earn enough money from it that we don't pay you anything for it, because with the dismantling of still usable components and the material recycling, especially steel scrap, (…) and also the (…) precious metals from the catalytic converters, enough money falls out of such an end-of-life vehicle that it is simply worthwhile for the recycler to be a collection point" (Man8). This perfectly illustrates that in a system where the product, in this case, a vehicle, does not return to the producer but ends up with a recycling firm, any DfX effort from producers primarily benefits the recycling firm.

*Effort level:* DfX innovation can mean that products need to be altered significantly, including not only materials, but often also product architecture. An example of this is the introduction of modularity as a design principle: "that also means that all our products are basically built in a modular system. This means that the operating elements are independent of the respective inserts and can be dismantled and then also partially reused (…)" (Con7). Completely redesigning products and altering product architecture can be significantly more complex than exchanging singular materials.

At this point, it is crucial to differentiate between complying with DfX regulations, i.e., demonstrating that one's products can be disassembled and recycled under laboratory conditions, and ensuring that they are recycled in practice. "So, it must be recyclable. That doesn't mean it will actually be recycled. That's an important and, unfortunately, very fine distinction" (Man8). Ensuring DfX in theory or under lab conditions already requires more complex innovation than the first two innovation categories presented in sections 4.3.1.1 and 4.3.1.2. However, it can theoretically be achieved through innovation within the production company itself, independently of other stakeholders along the value chain, such as customers or recycling firms (Figure 7, Figure 8). Ensuring products are, in the end, actually reused, refurbished, or recycled in practice is more complex than that. Compared to the previous two types of innovation, even more stakeholders need to be involved. Producers cannot simply design their products in an ivory tower because if products are designed in a way that recyclers either do not have the technology or the knowledge of how to treat them during the EOL phase, reuse, refurbishment, or recycling will not happen in practice and materials will ultimately end up being lost.

One of the interviewees confirmed this need for cooperation among different stakeholders, stating: "And yes, of course, the installation of our components, the dismantling, there are research projects on how this can be better designed, in which different players are now also involved" (Man9). From an innovation perspective, collaborating with additional external stakeholders outside one's own firms results in further complexity. This coincides with findings by Schmitt and Hansen (2018), who find that "circular as compared to conventional innovation requires the intense collaboration of an extended actor set consisting of internal and external constituents" (Schmitt & Hansen, 2018, p. 27).

In the construction industry, this means carpenters and demolition companies need to a) have a shared level of knowledge, b) have the technology to dismantle and separate products and materials easily, and c) also have the incentive to do so. Incentives, in this case, can either refer to a monetary incentive or a legal obligation enforced by governments. In the manufacturing industry, the same argument holds for repair shops in the case of, e.g., automotive products or scrap dealers/recyclers further down the value chain.

At this point, it is also important to zoom in on the differences between the two industries examined in this dissertation. Section 2.2.4 previously outlined many similarities between them. However, despite these many similarities, it also outlined significant differences in the circular value chain of the construction (Figure 8) and manufacturing industry (Figure 7). One of these differences is the additional layer in the construction industry's value chain consisting of architects, structural engineers, and developers that, together with the end-customer, highly influence the architecture and design of the end-product. As a consequence, they also influence whether it follows DfX standards. In the manufacturing industry, design responsibility, and therefore the responsibility to ensure DfX, is primarily within the hands of the producer or OEM. A producer in the automotive industry centrally decides about the architecture of its products. Consumers might be able to change the color of their vehicles or adapt the interior design, but they have no control over the overall architecture of the product.

This differentiation is important because, other than producers or OEMs in the manufacturing industry, architects, structural engineers, and developers in the construction industry are not inherently interested in designing for reuse, refurbishment, and recycling if no regulation forces them to. Even though sustainability and the CE have also become important considerations for architects in recent years, design aesthetics and individualism of their work remain at the core of an architect's job. Therefore, levers such as modularization (Con7) and standardization, which are ways to implement DfX in practice, may seem contrary to the aspirations of many architects in their work.

As a result, some of the interviewed producers in the construction industry reported that their marketing and sales departments had shifted the focus from simply selling circular products to educating stakeholders further down the value chain. Interestingly, ′exclusively interviewees from the construction industry reported the need to educate other stakeholders, including customers. For example, one interviewee explained: "We have to see that we really get access to the decision-makers, who have to understand certain arguments during the planning of the building to then tender things that we can then deliver" (Con10). Another interviewee, who initially had been in charge of the C2C certification of his company's product, also stated that they were involved more and more in the sales process: "Where I do a lot of education now is … um … towards our sales and product management [teams]. But above all in the direction of sales and partly also customers" (Con4). To bring the company's circular products to the market, one interviewee also pointed out that the company had to establish contacts with planners, architects, and other actors down the value chain (Con9).

The bottom line of this discussion about DfX innovation is the following: Demonstrating DfX can already be challenging for firms in lab settings, as it often requires changes in materials or product architecture. Ensuring that DfX results in closed loops in practice requires even more effort, as multiple stakeholders need to be involved, and their respective knowledge and technological capabilities need to be accounted for. Lastly, there is also a difference between the construction and manufacturing industries in terms of how much DfX is actually in the hands of the producing firms.

It becomes clear that innovation for DfX represents a significant challenge for companies. Producers face significant extra efforts innovating for DfX. The previous section has also shown that, at the same time, producers often do not profit from DfX, at least not monetarily, if they do not retain ownership of products or receive them back at the EOL. In fact, in this scenario, producers only have the motivation to comply with the regulation, that is, to ensure they can prove disassembly and recycling is possible within lab conditions. Any additional benefits would fall in the hands of recycling companies. This is a clear issue, as it means a decoupling of effort and benefits. This dilemma is accurately summarized by one interviewee, who argues, "(…) if the component can now be disassembled, then that's no use either if the business model doesn't allow it" (Man2). From an overall CE perspective, this is a severe problem, as DfX is nothing less than a prerequisite for the successful transition to a functioning CE. This leads us to the next category of circular innovation observed among the companies interviewed.

#### *4.3.1.4. Business Model Innovation*

In this dissertation, Circular Business Model Innovation (CBMI) is defined as "innovating the business model (e.g., updating the elements of an existing business model, or establishing a new organization and associated business model) to embed, implement and capitalize on circular economy practices" (Bocken et al., 2019, p. 3). One can argue that production process innovation, material innovation, and DfX innovation, as described in sections 4.3.1.1, 4.3.1.2, and 4.3.1.3, are also part of the business model. Still, this section only refers to those innovations that either radically changed or expanded a firm's business model.

Most companies interviewed openly admitted that their primary business model still followed linear thinking. While an interviewee from a car manufacturer explained: "in the end, this place earns its money selling cars" (Man4), another manager from a construction company similarly said: "At the end of the day, it is the business model to try and get access to construction projects to sell our product" (Con8). However, even though their primary business model remained mostly linear, many interviewees mentioned they had either recently introduced a CBM or were actively investigating opportunities to do so.

Business model innovation can be very complex, as many different elements of the business model can be altered to achieve higher levels of circularity. To increase clarity, this dissertation differentiates between upstream CBMI, downstream CBMI, and fully circular CBMI, following a taxonomy established by Urbinati et al. (2017). Upstream circularity in this taxonomy refers to non-customer-facing, mostly internal activities on the supply side (e.g., reverse logistics). Downstream circularity refers to the establishment of circular customer-facing activities concerned with the use and reuse of products. Fully circular business models refer to those that combine the two (Urbinati et al., 2017).

*Upstream Circular Business Model Innovation*

*Description:* One of the most important elements of upstream CBMI has been to gain access to secondary raw materials, i.e., materials that can be reused as input for new products. Companies that reported upstream CBMI mainly referred to their efforts to a) establish reverse logistics systems for EOL products (Man1, Man3, Man8) or b) create their own recycling facilities (Man4, Con8).

*Upside potential:* Urbinati et al. (2017) explain that the objective of upstream CBMIs is mostly improvements in the cost structure and cost efficiency. In countries with an established, well-functioning recycling infrastructure, third-party recycling companies are usually the ones who receive products at the end of their life and are tasked with disassembly, recycling, and recovery of materials. In these cases, material innovation, as described in section 4.3.1.2, is easily possible, and producers can simply purchase secondary raw materials from suppliers. However, if no adequate recycling infrastructure is in place, producers need to innovate their business model to ensure access to these secondary raw materials.

A notable example in the manufacturing industry is the production of electric vehicle (EV) batteries. Since new EU regulation requires OEMs to include recycled materials in their EV batteries (European Parliament, 2023), one interviewee explained: "In the future, (…) we have an interest in getting back the battery materials, for example. And there are already announcements from other OEMs that they will buy vehicles from other OEMs for their recycled batteries. In other words, they not only want to buy back their own brands, but the battle for these recycled batteries has already begun (…)" (Man8). Firms that have only focused on selling products for decades are now facing significant pressure to innovate their business model, establish reverse logistics systems, and innovate treatment for EOL products.

Interviewees from the construction industry, too, explained that their companies are addressing the shortage of recycled materials by entering the recycling business themselves. They have started to accept the demolition material and recycle it because it is an exciting business segment. If existing recyclers are unwilling or able, their motivation for CBMI is to ensure themselves that recycled materials are available in sufficient quantity and quality (Con10). Similarly, another interviewee explained that their company also built up its own recycling facility to ensure complete self-sufficiency in materials in the future (Con8). Such a vision can only be realized through a comprehensive CBMI.

A second reason for firms to establish reverse logistics systems or an upstream CBM can be the residual value of EOL products. *'Value'* in this case can refer to both the monetary worth of the materials themselves, which increases with scarcity, as well as to the value creation, such as welding or molding, that the product has already gone through. Regarding material value, as explained in section 4.3.1.3, rare or highly sought-after materials can be very expensive, and some firms simply choose not to leave these materials at the EOL to, e.g., recycling companies. Regarding EV batteries, one interviewee explained that establishing circularity is also monetarily attractive for OEMs, as batteries and virgin materials are expensive. It is not only about accessing the materials but also about a financial advantage of recovering them (Man5). Another player from the manufacturing industry similarly stated: "The other thing is that there are also quite a few areas where it is simply worthwhile, from the material point of view, that is, of course, predominantly when you have precious metals in there somewhere. This is actually often the case with sensors, which are used in many of these measuring devices, where platinum or something like that is contained somewhere" (Man3).

There are also cases in which the significant value creation (i.e., the manufacturing activities) that has already been invested into a product, and not only solely the material value, can justify the introduction of EOL take-back systems. In these cases, products can be remanufactured or refurbished and then resold at the same quality as new products. This allows producers to save costs on manufacturing activities such as welding or molding (Man1).

Sometimes, upstream CBMI can impact not only costs, as suggested by Urbinati et al. (2017), but also revenues. One company that introduced a take-back scheme for its products to recover secondary raw materials at the EOL realized it helped sales: "And, for example, we see this as a competitive advantage if we offer and establish a take-back system. Simply because the [customers] are experiencing a certain amount of suffering. And it's a great benefit for the [customers] if they can say: Here, [interviewed company] will take it back" (Man3).

*Effort level:* Innovating not only on a product level but reinventing or expanding the business model requires significant efforts from producers. An interviewee from the construction industry nicely explained: "We also have a project on how we can recycle the product ourselves. That is not exactly trivial from a technical point of view. (…) But the real hurdle is labeling, sorting, and getting the stuff back in a correctly sorted state" (Con4). One of the main barriers in this regard arises from the fact that, just like with DfX, offering reverse logistics systems and making them work in practice are two different tasks. The same interviewee went on to explain: “Everyone who has a take-back program … in reality, no products are coming back” (Con4). So, the real question is, how do you recover the products from customers at EOL? Or ideally, how do you get customers to actively return the products themselves?

This is already a challenge for producers selling their products in a B2B market, but for those with B2C sales channels, the task is even more complex. However, the firms in the sample that attempted to establish reverse logistics systems have shown very high levels of innovation in answering this question. Some of the firms interviewed established a deposit scheme for their products (Man1). Some are trying to leverage their retailers to establish reverse logistics processes (Man4). Others are experimenting with completely changing their business model from selling products to leasing them out instead (Man8). Almost all of the interviewees in both industries were also clear about the role digitalization would have to play and were actively innovating in the area of Digital Product Passes (DPP).

Given all these complexities, the question must also be asked whether upstream CBMI is a sensible thing for OEMs to do at all. Despite explaining that their company is actively engaged in battery recycling, one interviewee explained that with regard to the overall recycling of vehicles: “The third-party market will take care of that. (...) So there’s no point in deluding yourself that the OEMs will manage completely closed loops for automobiles themselves. They can’t do that, and they won’t” (Man4). This dissertation will take up this thought and attempt to answer the question of how firms can decide which circular innovations to implement in section 4.3.2.

*Downstream Circular Business Model Innovation*

*Description:* As briefly explained above, in the taxonomy of Urbinati et al. (2017) downstream circularity refers to customer-facing use and reuse activities, such as the introduction of pay-per-use models, while product design and internal activities within the firms remain largely unchanged. Therefore, this dissertation categorizes downstream CBMI as those activities concerned with the introduction of, e.g., rental or leasing options and those focusing on the sale of refurbished or reused products. One of the firms interviewed also experimented with decoupling the use and purchase of a vehicle (Man5), hence offering a PaaS model. Another, from the construction industry, stated there were active considerations within the company to move towards a more digital business model: "And [the digital business model] is, for example, something where we consider for the first time, to open this up more, to then potentially earn money with this platform, with this service and not from selling the goods" (Con9).

*Observed upside potential:* The most interesting aspect of the cases of downstream CBMI observed during the interviews is that interviewees were very clear that the primary motivation was the exploitation of additional profit pools. This coincides with findings by Urbinati et al. (2017), who see downstream circularity as a strategy for firms to expand revenue streams and penetrate into new market segments. For instance, one interviewee explained that offering reconditioned products is simply a significant business opportunity for the company (Man1). Another confirmed that the main motivation for establishing the company's rental business was to enter new business areas and to reach new customers and customer segments rather than a desire to become more circular (Man10).

Interestingly, primarily companies from the manufacturing sector have introduced downstream business models, such as rental, leasing, or the sale of refurbished products. This coincides with the latest research insights, which find business model innovation in the construction industry aiming to establish *material as a service* business models only to be attractive for "high-value materials and products with shorter life cycles or with global scarcity and competition" (World Economic Forum, 2023, p. 7).

*Effort level:* The effort required for downstream CBMI primarily differs from other innovations described in the sections above. Offering rental products, for example, can even be done for existing products that are not built with circular materials or do not follow DfX standards. In that sense, companies that pursue downstream business model innovation are often "focusing on the market acceptance of the pay-per-use model whereas no relevant changes are made at the level of product design, internal activities or suppliers” (Urbinati et al., 2017, p. 492). There are, of course, additional efforts needed to establish a downstream CBMI. Renting out products requires testing and reconditioning before they can be rented out again. These processes are new, and companies often need to establish them from scratch (Man10).

One additional complexity that requires attention when introducing downstream CBMIs relates to financing. One firm that had previously followed a linear business model highlighted that prolonging the cash cycle can be a significant challenge and is currently hindering them from offering life-long leasing options (Man8). In a linear business model, there are only months between purchasing materials for production and the date of sale. Choosing to establish a downstream CBMI and offering leasing options instead means that revenues come in over a longer period of time instead of at once. Prolonging cash flows like this leads to significant implications for the firms' working capital and subsequently requires significant efforts on the financing side (Man8).

*Fully Circular Business Model Innovation*

The fully circular business model combines both the upstream and the downstream considerations. Therefore, innovation for a fully circular business model combines the complexity of the two but also offers the benefits of both. Interestingly, they can be very strongly interlinked. Innovation of a downstream business model, such as introducing rental or leasing products instead of selling them, can help companies penetrate new customer segments and gain a competitive advantage. Additionally, this approach ensures that producers retain ownership of the products and materials. This was confirmed by an interviewee who suggested that the company's introduction of leasing as a new business model could also be a way to recover both the products and materials at the end of life (Man5).

From a Circular Economy perspective, only a fully circular business model offers the possibility of reducing waste to zero and allowing resources to flow in closed loops. An upstream CBMI for non-circularly designed products extends their life cycle. Still, if products are not designed with DfX aspects in mind, a true Circular Economy, as the C2C concept (McDonough & Braungart, 2002) strives for, is not possible.

#### *4.3.1.5. Summary of circular innovation types*

The previous sections have shown that innovation for the CE can take various forms. Four main types of innovation were identified from the interviews: *production process innovation*, *material innovation*, *DfX innovation,* and *business model innovation*. While the first three categories are possible without significantly altering the firms' business model, the fourth category, as the name already suggests, refers to expansion or radical changes in the business model. Figure 19 provides an overview of these findings.

| | Level 1: Production Process Innovation | Level 2: Material Innovation | Level 3: DfX Innovation | Level 4: Circular Business Model Innovation (CBMI)<br>Level 4a: Upstream CBMI | Level 4b: Downstream CBMI |
|---|---|---|---|---|---|
| **Description** | Innovation in the production processes to enable pre-consumer waste recycling | Innovation for circular (renewable or recycled) materials<br>Either as part of own R&D activities or by changing requirements towards suppliers | Design innovation (product architecture, materials, etc.) to facilitate re-use, refurbishment, and recycling at the end-of-life | "Innovating the business model (...) to embed, implement and capitalize on circular economy practices" (Bocken et al., 2019)<br>Innovation to gain access to circular materials (e.g., establishing reverse logistics systems or recycling plants) | Innovation of customer-facing business (e.g., rental or leasing business models or sale of refurbished/re-used products) |
| **Potential Firm Benefit** | **Low**<br>Overall low, depending on amount of pre-consumer waste<br>Opportunity to decrease virgin material needs and avoid waste treatment fees | **Medium**<br>On revenue side (significant and increasing demand for products with circular materials)<br>On cost side: Some secondary materials in fact cheaper; avoiding fees for non-compliance with circular min. requirements | **Low**<br>Huge upside potential for overall CE (pre-condition for mechanical recycling)<br>Partial revenue upside (demand for DfX products)<br>Producers only really profit from DfX if product ownership is retained or products return EOL | **High**<br>Significant cost savings and efficiency potential (Urbinati et al., 2017) especially for sought-after or valuable materials<br>Offering take-back systems can also be competitive advantage (disposal as pain-point for customers) | **High**<br>Focus on exploitation of additional profit pools and penetration of new market segments with refurbishment, rental, pay-per-use, etc. offers (Urbinati et al., 2017) |
| **Effort Level** | **Low**<br>Innovation largely independent of the product (only changes to production processes)<br>Effort level depends on if recycling processes exist for production waste or not | **Medium**<br>Depended on if material R&D is conducted in-house or passed onto suppliers<br>In both cases significant testing & certification efforts necessary in construction & manufacturing industry if materials are changed | **Medium/high**<br>Significant, often beyond material innovation but innovation of product architecture/design instead<br>DfX under lab conditions already challenging, making it work in practice even more so | **High**<br>Very significant, especially getting products back in correct state (even more so B2C products)<br>High potential for digitalization to reduce these efforts in the future | **Medium/high**<br>Can – in theory – be done with existing, non-circular products (extending life-cycle)<br>Largely effort in marketing & sales divisions of firms<br>New processes required for take-back of e.g., rental products |

**Figure 19: Cascading framework of innovation types observed in the sample[26]**

[26] Source: Author's illustration

### 4.3.2. The decision-making process for the implementation of circular innovations

The previous section has shown that innovation types identified among the sampled CE frontrunners differ in terms of the effort required to implement them, the potential benefits they offer to individual companies, and their possible contribution to increasing overall circularity rates. Each type provides a legitimate path to implement the CE for an individual company. The big question, especially for companies that have not yet implemented CE on a large scale but are looking to begin with CE implementation, is how they can decide which of these circular innovations they should pursue (RQ 2.2).

Significant research has attempted to identify ways to help companies make the correct strategic decisions within the field of sustainability (Calabrese et al., 2019). For the CE specifically, a significant contribution has been made by Corona et al. (2019), who reviewed various measurement indices, assessment indicators, and assessment frameworks that have been designed over the years. Circularity assessment indicators and frameworks "are usually applied to determine which circular strategy should be favored, or whether the adoption of a circular strategy would increase the sustainability of an existing system" (Corona et al., 2019, p. 5). While all these indicators and frameworks represent important and valuable tools, their primary purpose has largely been to assess the circularity of a system, i.e., they are mostly evaluating material recirculation rates or the circularity degree of an existing system (Corona et al., 2019).

This dissertation aims to determine if there are any additional dimensions beyond an innovation's contribution to circularity that need to be considered in the decision-making process for implementing circular innovations on a company level. The following section will summarize the dimensions that interviewees and literature consider important in a more holistic circular innovation assessment framework, thereby contributing to the second research question (RQ 2) of how firms can leverage innovation for the implementation of the CE in practice.

#### *4.3.2.1. Contribution to circularity as the cornerstone of the framework*

In the search of developing a framework for decision-makers on the company level, an important question is which dimensions are relevant for a decision on the implementation of circular innovations and should hence define its cornerstones. As the framework is first and foremost meant to assess circular innovations, its first dimension should unarguably be that of an innovation's contribution to overall circularity. Therefore, decision-makers should, first of all, ask themselves the question: Does the innovation contribute to circularity?

When assessing this question, it helps to go back to the ultimate goals of the CE: minimizing resource inputs and waste, emissions, and energy leakage (Geissdoerfer et al., 2017, p. 764). If an innovation has the potential to fulfill one or, ideally even all of these criteria, it can, per definition, be considered to enhance circularity, at least in some way. Measuring the extent to which an innovation contributes to circularity can be anything but an easy task. Multiple reviews have examined different circularity indices and metrics or attempted to develop new ones (Cayzer et al., 2017; Corona et al., 2019). However, with many circularity metrics focusing particularly on material recirculation and recycling rates, they fail to include the other dimensions of the CE, such as the reduction of emissions and the overall virgin resource consumption.

It would be beyond the scope of this dissertation to evaluate the various circularity metrics. Still, it is worth pointing out that while concluding that no metric perfectly captures all the goals of the CE, Corona et al. (2019) have found the LCA framework to show high potential in addressing the goals. Either way, this dissertation proposes to make the question of whether an innovation positively contributes to circularity the first question to answer for firms looking to decide about implementing circular innovations. If the answer to this question is 'no' and the innovation does not enhance circularity as defined above, it should not be pursued from a circularity perspective.

#### *4.3.2.2. Monetary considerations as another key factor for many firms*

In addition to circularity, both literature and interviews indicate that for most firms, the monetary dimension is of utmost importance when deciding which innovations to implement. Circular innovations are no exceptions to this. Sections 4.3.1.1 to 4.3.1.4 have already shed some light on the decision-making processes of the firms interviewed. Even among CE frontrunners, most interviewees have clearly stated the importance of monetary value in their decision-making process. "Something that is more expensive today, and this begins at one cent extra cost, is typically rejected" (Man2). The same interviewee later even argued: "To reduce any kind of margin because of sustainability or circularity is not an option here" (Man2). Likewise, an interviewee from the construction industry confirmed: "There needs to be a return on investment. If the return is not there, some things just won't happen" (Con2). This suggests that, in practice, firms tend to reject any circular innovations that do not generate a positive short-term ROI. These insights resonate with findings from Kirchherr et al. (2017), who found the CE definitions to over-proportionally focus on economic prosperity, only followed by environmental quality.

Examples from practice confirm the emphasis on the monetary dimension. To help decision-makers choose between different GHG emission reduction alternatives, leading strategy consultancy McKinsey & Company has proposed the Marginal Abatement Cost Curve (MACC) (Figure 20). Even though the MACC was initially developed for CO2 abatement, it can easily be translated to the example of circular innovation, as both concepts, in their essence, focus on avoiding negative externalities. One of the critical goals of circular innovations is to reduce waste creation (Geissdoerfer et al., 2017), while the MACC maps initiatives to reduce $CO_2$ pollution. The MACC maps “estimates of the prospective annual abatement cost in euros per ton of avoided emissions of greenhouse gases, as well as the abatement potential of these approaches in gigatons of emissions” (McKinsey & Company, 2007). The authors go on to argue that their “analysis assumes that the focus would be to capture all of the cheapest forms of abatement around the world but makes no judgment about what ought to be the ultimate distribution of costs“ (McKinsey & Company, 2007). Furthermore, the concept acknowledges that some measures, especially those around efficiency improvements, can lead to negative abatement costs, effectively saving money for the respective firms.

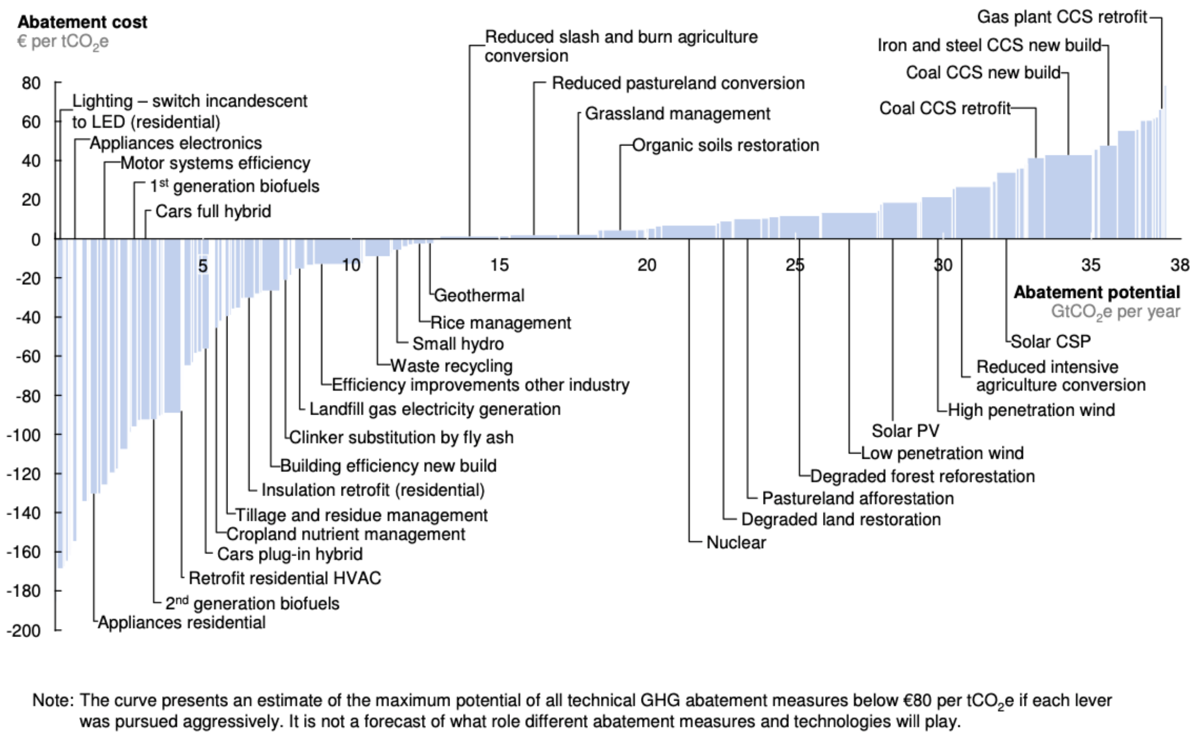



**Figure 20: McKinsey's Global GHG abatement cost curve version 2.1[27]**

The MACC is used as an example because it helps to illustrate how firms could assess the cost dimension of circular innovations. In an illustrative example, a firm that faces the decision of whether to implement either production process innovation or material innovation could plot each innovation's cost and its waste reduction potential on the MACC to compare and then derive their conclusions. Both, interview insights and concepts, such as the MACC, underline the significance of monetary value when assessing innovations. It is only natural that a profit-oriented firm will want to achieve the highest impact on circularity with the lowest possible investment.

However, as with any other investment decision, firms must also consider the time dimension when evaluating an innovation's potential to create monetary value. An interviewee from the construction industry explained that the company's decision to innovate its business model and build its own recycling plants was not profitable for a long time. The decision only paid off after numerous years, illustrating the long-term perspective the company had taken when deciding to implement such business model innovation (Con8). However, interview data shows

[27] Source: McKinsey & Company (2010)

that many companies are still short-sighted when making decisions about circular innovations and are too focused on their short-term stock performance. This translates into a lack of an adequate long-term perspective (Man5). Therefore, any framework to decide on circular innovations can never be static. Depending on the time horizon, the value of each circular innovation will differ.

Acknowledging that most interviewees highlighted the importance of the monetary dimension for the implementation of their circular innovations, this dissertation proposes to include monetary value as a second dimension in the decision-making framework.

#### *4.3.2.3. More to business value than monetary value*

The question is whether accounting for circularity and monetary value is enough when making decisions about circular innovations. Should solely these two dimensions define the decision about circular innovations on a firm level, as, e.g., the MACC would suggest? The answer is no. Already in the quantitative study, this dissertation extensively argues there is more to firm performance than the financial dimension (compare section 3.4.4). The findings from the interviews also confirm this. For example, one of the interviewed firms from the manufacturing industry had established a product-take-back system at the EOL, subsequently disassembling and recycling the products. This upstream CBMI was established to get access to valuable materials, but more importantly, because disposal of the product at the EOL had previously been a significant pain point for its customers (Man3). For the interviewed firm, the monetary dimension was not the deciding factor to implement the circular innovation. “It’s not so much a question of whether it's profitable for us. (…) It’s not that recycling would be profitable or anything like that, but it’s a sales argument and a special customer service, so to speak” (Man3). Another interviewee explained that despite the company’s clear intention to generate profits, one of the main goals behind the decision to implement an upstream CBMI was to ensure material self-sufficiency and independence of supply chains in the long run (Con8). In both cases, circular innovations were motivated by a strategic reason rather than an opportunity for financial gain.

Furthermore, many of the CE frontrunners in the construction sector, especially those below the size of a multi-national corporation (MNC), have reported that their decisions to implement circular innovations have been based on the attempt to generate a unique selling proposition (USP) and hence a competitive advantage over their competition. “We developed our product portfolio under these aspects and, in the end, tried to generate unique value propositions for which we pretty much knew that competitors could not … at least not from a time perspective … could not just hop on board and take the business away from us (…)" (Con5). Others explained: "So that we also asked ourselves, first of all from a marketing perspective, how can we differentiate our product" (Con2). These attempts to use circular innovations to create a USP are, of course, not free from any monetary considerations, as these companies hoped for their competitive advantage to ultimately result in a financial benefit. However, their main motivation was often not purely financial but instead more strategic.

The above-mentioned observations from the interviews confirm that, among CE frontrunners, there are other motivations than purely monetary ones to pursue circular innovations. Firms should consider implementing circular innovations, even if they do not generate immediate profits, as long as they are expected to create significant business value in the near future. This value could be in the form of a substantial sales argument, marketing opportunity, a unique selling proposition, or supply chain independence. Therefore, this dissertation proposes to add a third dimension to the framework, referred to as *non-monetary business value of circular innovations*. Figure 21 shows an intermediate state of the framework, depicting the three dimensions identified so far:

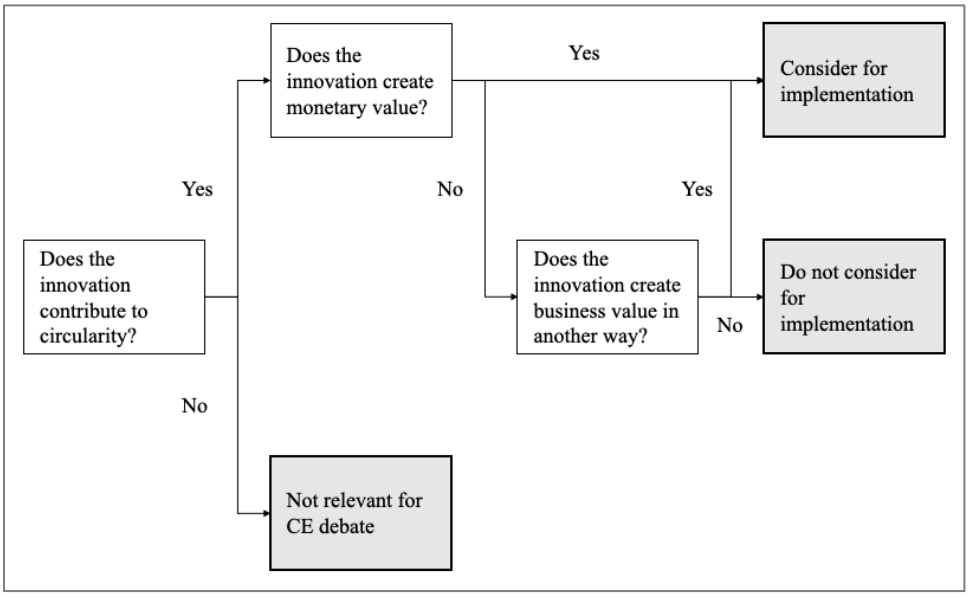



**Figure 21: Adding a third dimension to the decision-making framework for circular innovations[28]**

[28] Source: Author's illustration

#### 4.3.2.4. Accounting for shared value creation

Should firms implement all innovations that contribute to circularity on the one hand and to business value, be it monetarily or in another way, on the other hand? The answer to this can still be no. Some innovations create business value and contribute to circularity, but CE frontrunners in the study sample have still decided not to pursue them. During one of the interviews, an interviewee explained that the company had actively decided against implementing an upstream CBMI to take back its products, as intensive LCA had revealed that incineration proved to be the least $CO_2$-intensive EOL treatment for the company's products. "If I start off with a very small [ecological] footprint, with (…) ecologically cheap materials – I am not talking about the monetary value – if I return, for example, [the company products] from the US, where we sell them, the sorting, the freight cost and so on generate a larger ecological footprint (…) than if I would simply produce them newly" (Con4). In this case, the firm decided against a circular innovation, irrespective of monetary or business value, but added the dimension of environmental meaningfulness.

To understand the reasoning behind such a decision, it makes sense to look at research in the wider sustainability literature. Porter and Kramer (2006) have researched within the field of Corporate Social Responsibility (CSR) to answer the question which CSR measures firms should implement. They subsequently developed the *shared value* concept, which "involves creating economic value in a way that also creates value for society by addressing its needs and challenges (Porter & Kramer, 2011, p. 4)". Even though the shared value theory focuses on firms' CSR agendas, it is a concept that can also be applied to the decision-making in the context of circular innovations. In fact, other researchers have previously also argued for a connection between the CE and the shared value concept (Akpinar, 2020). Porter and Kramer (2006) state that "the essential test that should guide CSR is not whether a cause is worthy but whether it presents an opportunity to create shared value that is, a meaningful benefit for society that is also valuable to the business" (Porter & Kramer, 2006, p. 10). In other words, they emphasize the importance of business value but add a dimension that they name *societal value*.

This reasoning is in line with the example cited above (Con4) of a company deciding against introducing a circular business model in its overseas markets because the CO2 impact from logistics would have exceeded that of new production. Although the CE naturally endeavors to combine economic, ecological, and social objectives (Kirchherr et al., 2017), there may also be isolated circular innovations that do not generate any added value from a social or environmental perspective. In line with this rationale, innovations that contribute to circularity and create business value but may have a negative social impact should also not be implemented by firms looking to innovate for circularity. Therefore, an additional fourth dimension should be added to the decision-making framework, assessing the innovation's contribution to environmental/societal value (i.e., shared value).

##### *4.3.2.5. Recommendation for a decision-making framework*

To summarize, sections 4.3.2.1 to 4.3.2.4 demonstrate that CE frontrunners in the construction and manufacturing industries evaluate four dimensions when deciding whether to implement circular innovations. This section briefly outlines each of the four dimensions and integrates them into a decision-making framework comprising four stages.

In stage 1, firms should evaluate an innovation's potential to contribute to circularity. For this purpose, many different metrics have been developed. A helpful overview and assessment of such metrics is provided by Corona et al. (2019) (compare section 4.3.2). If an innovation is found to enhance circularity, firms should move to stage 2 of the decision-making process.

As most firms intend to make profits, it is only reasonable to assess in stage 2 whether the circular innovations in question can generate monetary returns or, in other words, an ROI. During this assessment, keeping a long-term perspective and not focusing solely on potential short-term costs is crucial. Nevertheless, if a circular innovation does not promise to generate monetary value in this second stage of the framework, it should not be discarded immediately. Instead, decision-makers should consider if the circular innovation could generate non-monetary business value that could justify its implementation. If firms conclude that a circular innovation will most likely neither add monetary value nor generate (enough) business value to make up for its initial costs, they cannot be expected to implement it. In this case, they should not consider the circular innovation for implementation. However, if a circular innovation is either likely to generate monetary value (stage 2) or significant non-monetary business value (stage 3), it should move on to stage 4 of the framework.

In this last stage, decision-makers should assess whether the circular innovation also has an ecological and societal meaningfulness in the sense that it contributes to shared value generation. If this question can also be answered with a yes, firms should implement the circular innovation in question. The following framework summarizes these dimensions in a decision-making tree (Figure 22).

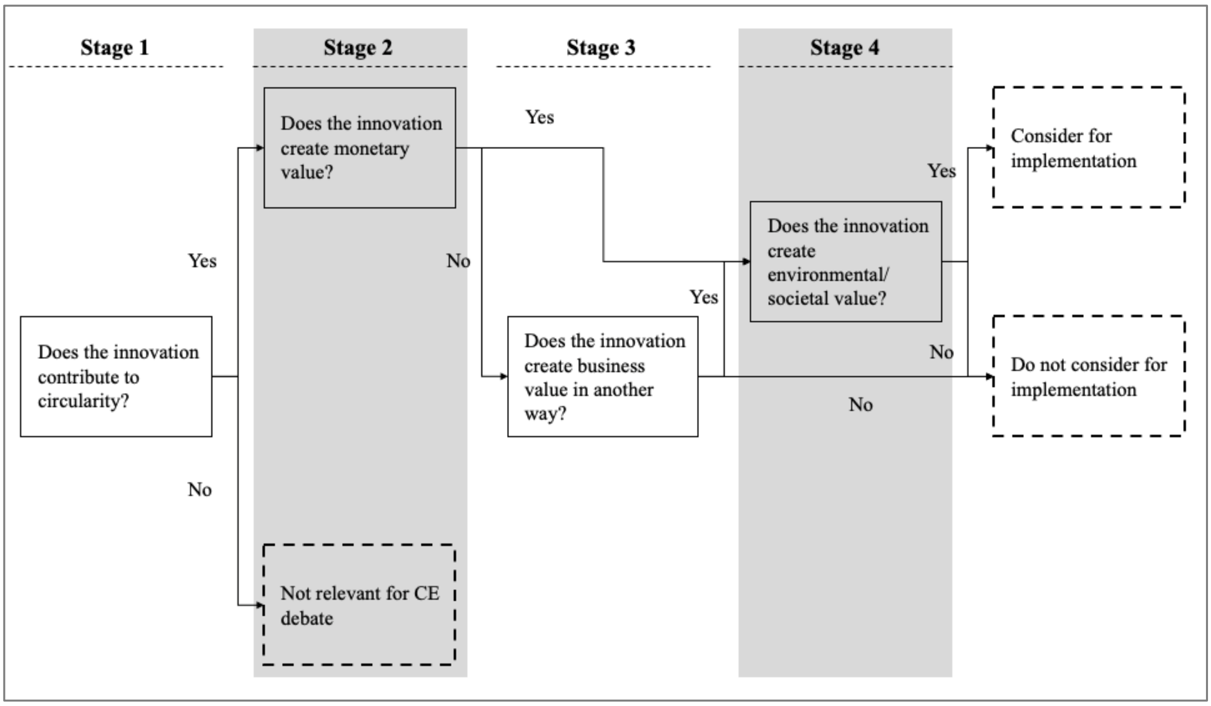



**Figure 22: Proposed framework to decide on the implementation of circular innovations**[29]

### *4.3.2.6. Prioritizing the circular innovations that pass the decision framework*

The framework in Figure 22 shows that the decision-making process for circular innovations highly depends on the context in which each firm operates. Therefore, it can be very different across industries, firms, or even products. However, it is possible that more than one of the identified circular innovations passes through the framework and firms decide that, for example, both production process innovation and upstream CBMI should be considered for implementation. If this is the case, how should firms, which are already in a constant struggle to allocate resources such as cash, workforce, and time, prioritize the circular innovations? To illustrate this further, one interviewee explained that so far, his company could only implement incremental circular innovations instead of complete disruptions: "(...) because of these underlying conditions: fully utilized production capacity, the production processes as such are, of course, also continuous, the production lines are over 50 meters long, up to 100 meters long depending on the size, and it's difficult to make a quick change to say: I'm going

[29] Source: Author's illustration

to try something out" (Con2). The company, in this particular case, was simply limited in its economic capacity, undoubtedly also due to its size, and therefore could not implement disruptive circular innovations, even if they might have created significant business value in the long run.

In cases like these, where only scarce resources are available, companies need to prioritize. Tools like the MACC can aid in comparing circular innovations across dimensions, such as their potential to contribute to circularity and generate monetary value. However, examples from the interviews have demonstrated that other dimensions, such as time or availability of labor, can also impact prioritization. Exploring how CE frontrunners prioritize circular innovations could be an interesting aspect for future research to address, but it is beyond the scope of this dissertation to develop a suggestion on prioritization. Instead, it is important that companies a) realize that all circular innovations that pass the proposed decision-making framework (Figure 22) will add value and b) that they commit resources to drive their implementation forward.

The recommendations from sections 4.3.1 to 4.3.2.5 are summarized in the following graphic, illustrating the three important steps firms in the construction and manufacturing industry should take when evaluating circular innovations (Figure 23). First, companies need to gain an overview of the types of circular innovations available to them. Second, they need to assess each innovation's contribution to circularity, business value, and environmental and societal value to establish whether its implementation would be sensible. Last, companies need to rank or prioritize the implementation of innovations according to their own preferences and business circumstances.

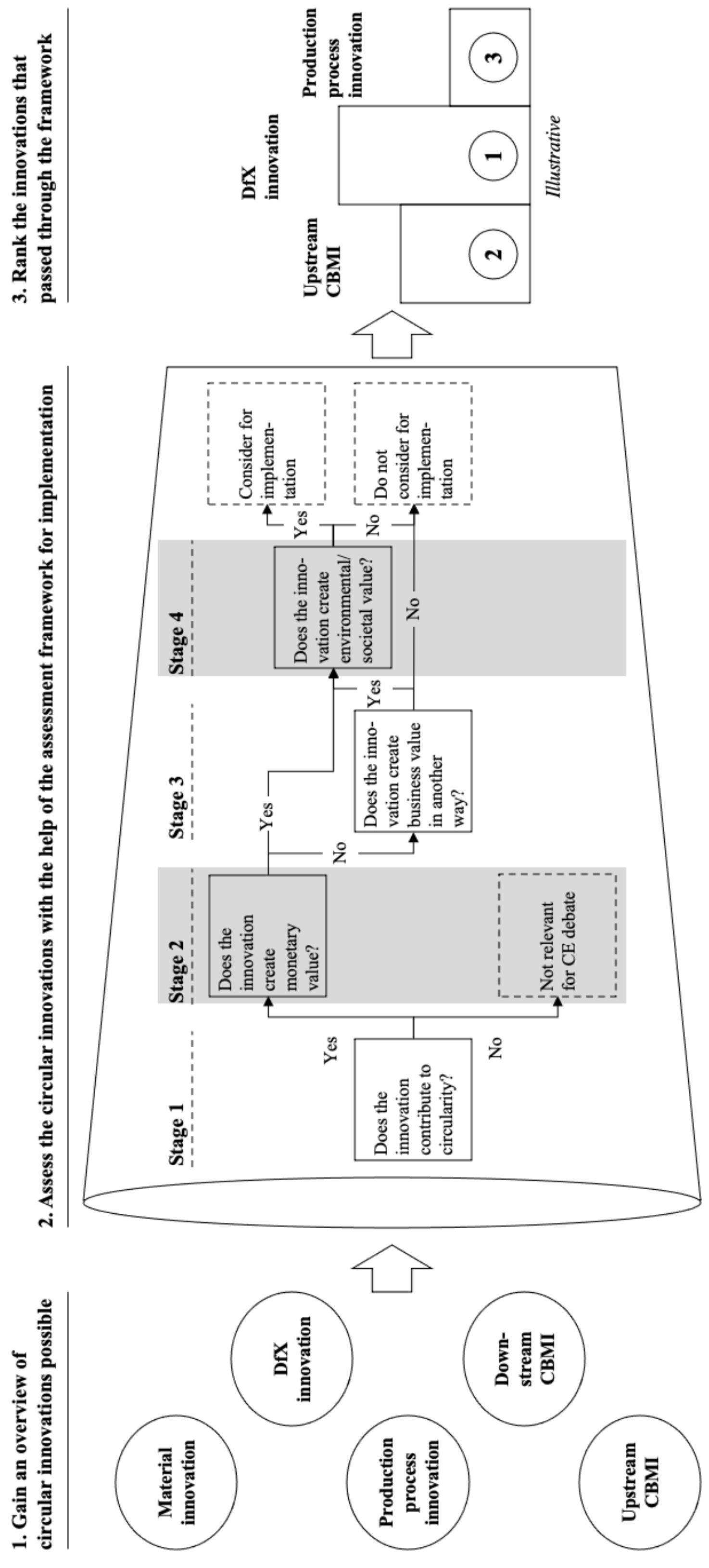



**Figure 23: Summary of the steps firms should follow to assess circular innovations[30]**

[30] Source: Author's illustration

### 4.3.3. Innovation capabilities identified among CE frontrunners

The previous sections have outlined an approach to help companies select circular innovations for implementation. The key question that remains is how to implement them. How have the CE frontrunners approached implementation, and what insights can be derived for companies seeking to implement either type of circular innovation themselves?

This final part is essential to provide a comprehensive answer to the question of how firms can leverage innovation for the implementation of the CE (RQ 2). Therefore, the sub-research question RQ 2.3 asks: *Which innovation capabilities can assist firms in implementing circular innovations?* This ties back directly to the previous finding from the PLS-SEM analysis that innovation capabilities have a significant positive effect on CE implementation in the construction and manufacturing industries (compare chapter 3).

The following section presents an overview of specific innovation capabilities that the CE frontrunners have applied at the firm level. For innovation practitioners trying to implement the CE, it shows concretely what can be done. This dissertation takes explicitly a micro-perspective and focuses on those capabilities that firms themselves can influence. It consciously does not include the macro-level practices or enablers for, e.g., governments or legislators, as sufficient research has been done in that area (Circular Economy Initiative Deutschland (Ed.) et al., 2021).

Before diving into the findings from the qualitative study, it is worth revisiting the definition of innovation capabilities: "An innovation capability is therefore defined as the ability to continuously transform knowledge and ideas into new products, processes, and systems for the benefit of the firm and its stakeholders" (Lawson & Samson, 2001, p. 384). In other words, given the findings in chapter 3 that innovation capabilities can positively influence the implementation of CE, firms need to find ways to enhance this ability to transform knowledge and ideas into innovation.

To make this more tangible, it helps that the literature does not propose innovation capabilities as a stand-alone construct but rather as the result of many different activities in a firm. Concretely, seven elements have been proposed to constitute innovation capabilities: "vision and strategy, harnessing the competence base, organizational intelligence, creativity and idea management, organizational structure and systems, culture and climate, and management of technology" (Lawson & Samson, 2001, p. 388). This dissertation argues that pulling the right levers along these seven elements can be a way for firms to enhance their innovation capabilities and, therefore, improve their CE implementation. The following sections summarize the findings from the interviews with the CE frontrunners, clustering them into the seven elements proposed on the left-hand side of Lawson and Samson's (2001) innovation capability model (Figure 10).

#### *4.3.3.1. Vision and strategy*

The interviews reveal that various firms, implementing different circular innovations, have faced unique challenges, and have therefore developed distinct capabilities to overcome them. Nonetheless, the decision to implement circular innovations was in most cases a strategic one. Section 4.3.2 extensively examines how firms can navigate the decision-making process for circular innovations. There are, however, exciting practices in the area of corporate strategy beyond the concrete decision about the implementation of circular innovations that have helped the CE frontrunners in their overall transformation. This includes *taking a long-term perspective and developing a long-term strategy*. One interviewee reported: “My boss has launched a program two years ago, which is about developing a vision: Where do we stand in ten years or in five years and how does construction look like then” (Con9)? For the manufacturing industry, another interviewee similarly suggested that a shift towards CE requires questions to be asked, such as: “Hey, do we even still exist in 50 years? (…) What is our role then if Google develops the autonomous driving (…)” (Man4)? Such strategic foresight should be practiced in all companies, even those following linear business models. However, only a long-term perspective reveals challenges such as material shortages, increasing price instability, or changing customer demands, which have been among the reasons for CE frontrunners to introduce circular innovations. For the companies surveyed, the need to introduce circular innovation only became apparent when they took a long-term view and engaged in foresight.

Moreover, in many cases, it has proven to be a critical success factor to *anchor CE centrally in the firm’s strategy* (Con3, Con5, Con8). This illustrates that changes, as profound as the implementation of circular innovation, require central support. While comparatively small circular innovations, such as production process innovation or material innovation (compare Figure 19), can sometimes be implemented in individual departments, implementing e.g., DfX or business model changes is almost impossible without central backing.

Similarly, some CE frontrunners described *anchoring sustainability/circularity in the companies' vision or mission statement* positively affecting the success of circular innovations (Con2, Con4, Man3, Man 5). Interestingly, one interviewee reported the mission statement to be the result of top-down decisions from the owner of the firm (Con4), while another participant reported the importance of a bottom-up initiative by employees: "Our mission statement is an essential component (…). The mission statement is updated regularly. (…) For that, all employees (…) are invited to ask the question: Are the values that we have still contemporary? What needs to be added? What needs to change" (Con2)? The interviewee later added: "The old mission statement was still good (…), but the focus on sustainability has been moved forward simply because this is something that grows from within the team, in other words, from us" (Con2). This dissertation cannot provide insight into whether a top-down or bottom-up initiative is more effective, but embedding the CE in the vision/mission appears to be an effective way to provide a North Star for the company's innovations.

The last innovation practice identified among CE frontrunners in the area of company strategy is *experimenting, developing concept products, and testing in small sample sizes* for circular innovations. This was observed both in the automotive (Man1, Man8) as well as in the construction sector (Con9). It has proven necessary to demonstrate the viability of some of the CBMs (Man8, Con9) and counter the widespread skepticism in many firms. Such proofs of concept (PoC), which demonstrate the potential of circularity, can also be a great way to inspire future circular innovations and to anchor circularity in the company's vision.

#### *4.3.3.2. Harnessing the competence base*

This category, harnessing the competence base, refers to "the ability to correctly and effectively direct resources to where they are required" (Lawson & Samson, 2001, p. 390). One of the key capabilities in this area concerns effectively *harvesting and incorporating learnings from circular innovations*. Across both industries, companies explained that introducing circular innovations had generated significant knowledge for them, which will significantly assist future innovations in the field of CE. Interviewees referred to knowledge about the certification process of circular products (Con4), knowledge about the introduction of CBMs (Man9), and knowledge from their own upstream CBMs about product dismantling and recycling (Man8). Gathering this knowledge and ensuring that future innovations profit from it is critical to staying in the position of a CE frontrunner and retaining an advantage over the competition.

*Ensuring sufficient financing for the implementation* of circular innovations and innovatively exploiting funding channels is also critical. Among the CE frontrunners interviewed, particularly companies in the construction industry mentioned this aspect. Some ensured sufficient financing through an active search for investors (Con1, Con3), while others highlighted the advantages of being a family-owned company (Con2) and, therefore, the ability to tolerate a longer period until break-even of circular innovations (Con8). Once again, looping back to the discussions in earlier sections, financing has a critical and unique role for circular innovations, particularly in light of an ongoing debate around their business case and break-even points (section 3.1.3).

##### *4.3.3.3. Organizational intelligence*

Concerning organizational intelligence, *analyzing the competitive landscape* has been named as a basis for the success of circular innovations (Con1, Con2). This might not necessarily be a CE-specific practice. Still, this dissertation nonetheless considers it valuable, as it has helped CE frontrunners identify the market gap for their products and business models. One interviewee gave the example of how such an analysis had been the basis for their company's decision to develop a C2C-conform product. The company realized that, from a perspective of environmental product performance, no competitors had comparable products, and it would take them years to develop a competitive alternative (Con5).

Similarly, *setting up a future-oriented radar to anticipate trends* regarding technologies (Con5), as well as customer demands and societal developments (Man5, Con9), has been presented as a way for CE frontrunners to be ahead of their competition regarding circular innovations. One interviewee explained in more detail: "And we try to anticipate that to a certain degree in the sense that we opened up a trend-radar (…). And one of these societal trends can, for example, be a sustainability trend where customers ask themselves: Can I separate [the company's products], can I dismantle them by material again [at the EOL]" (Con5)?

Furthermore, *screening universities and start-ups for circular innovations* has been mentioned on one occasion as a way to identify new innovations, particularly in the field of new materials (Man8). One could hypothesize that the novelty of the CE concept could mean that universities or start-ups do a comparatively high share of innovation. The ability to harvest and internalize knowledge from external sources, such as universities or start-ups, is therefore crucial, especially in the area of CE.

While the above-mentioned capabilities might suffice to successfully innovate in a linear economy context, almost every single CE frontrunner mentioned an additional aspect to circular innovations in particular. It refers to *screening the legal environment and anticipating upcoming laws and quotas*. Resulting from the fact that governments and regulatory institutions in Germany and the EU are increasingly realizing the urgency to transition to a CE, more and more rigorous regulation and legislation has been introduced in recent years (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2020; Directive 2008/98/EC, 2008). CE frontrunners in both industries are actively adapting their products to respond to these regulations (Con10, Man4, Man8), while some are even trying to anticipate upcoming regulations in their product developments (Con6, Man2, Man9).

#### *4.3.3.4. Creativity and idea management*

Creativity and idea management is the next element in the model of innovation capabilities (Lawson & Samson, 2001). Allowing a certain *freedom to innovate and experiment* (Con2, Man2, Con9) can be argued to be the basis for all successful circular innovation. One interviewee nicely summarized: "You cannot stuff creativity into project management. There need to be the right ideas, the right people, and a motivation" (Con4).

A very interesting approach in this regard has been mentioned by two interviewees who have advocated for *introducing a frugal mindset in innovation***,** reducing unnecessary complexity in product design (e.g., reducing variety of materials), requirements, and processes (Con3, Man2). While previous research has made the case to link frugal innovations and sustainability, researchers acknowledged that particularly the efficiency and sufficiency dimensions link the two concepts (Rosca et al., 2018). Even though other schools of thought, such as the C2C concept (McDonough & Braungart, 2002), argue for effectiveness rather than efficiency in a CE, unarguably reducing unnecessary or overly complex technical requirements, and thus following frugal principles as suggested by Achtelik et al. (2023), can be a way to accelerate circular innovations.

The interview questionnaire also included a question of whether the companies have tried to train or educate employees to support the innovation process for circular products (compare Appendix B). However, few interviewees reported any specific activities with regard to training. Only one interviewee explained that the company had actively tried to establish an innovation culture and equip employees with innovation capabilities by *launching a dedicated training program* (Con9). Others stated that despite the company's significant progress in introducing C2C products, there were currently no specific training to build up any capabilities in the area, speculating that these might come in the future (Con6). Although only one company mentioned they were actively building up capabilities in this area, it is worth noting that there are many tools available to improve creativity and idea management. This is an area that companies can influence and develop if they want to.

Another way to promote innovation is to create a dedicated space, for example, by *establishing a dedicated innovation business unit or team* (Man8). Especially for large corporations, who have the necessary resources and are looking for ways to escape rigid silo and layer structures, this can be an effective way to dedicate a safe space to innovation. Such a strategy can prove particularly effective in addressing significant challenges such as developing circular products or business models.

#### *4.3.3.5. Organizational structure and systems*

Firms constantly adjust their organizational structures, often intending to respond to external influences and challenges and become more agile. With regards to structural changes that have helped to implement circular innovations specifically, respondents frequently referred to *connecting business functions and breaking down silos* between said functions. One interviewee explained the importance of bringing multiple business functions together early in the innovation process (Con2). For SMEs, which are smaller in size, having all business functions in one location and having a small overhead can be an advantage in this situation (Con5). Large MNCs that are spread over multiple locations or even geographies have to make an active effort to break down these silos. In this context, *flat hierarchies* were also mentioned on multiple occasions as essential for the success of circular innovations (Con2, Con6, Man2).

Tying in perfectly with the argument above, those CE frontrunners that had already established CBMIs (i.e., product-take-back schemes or refurbishing and remanufacturing services) reported that *involving business units dealing with product take-back in product innovation* can generate significant knowledge, which would be impossible to harvest in linear business models (Man1, Man8). One interviewee explained the importance of connecting the R&D department with the firm's remanufacturing division and highlighted the valuable insights for

DfX and material innovation generated from closer collaboration between the business units (Man1). The benefits resulting from this collaboration relate to the fact that the companies' R&D departments suddenly have access to hundreds or even thousands of data points about their products' wear and tear. The same interviewee pointed out that for the firm's R&D department, getting access to returned products through a CBM means nothing else than a large field trial that can help to improve not only circularity (e.g., product architecture and design) but also durability and quality of future products (Man1).

With regards to accelerating the transition to a CE, multiple interviewees also pointed out that they have *established dedicated teams/programs with a CE/sustainability focus* (Con5, Man4, Man6). However, it is not only about establishing such teams but, even more importantly, about *integrating them with existing business functions and processes*. If dedicated CE/sustainability teams are involved early in the innovation process, their influence on DfX and other decisions can be significant (Con5). However, suppose they operate separately and are not involved in the important decisions at the right time. In that case, there is a risk that they remain ineffective and lead to marginal improvements only. Multiple interviewees, particularly from the manufacturing industry, have suggested that establishing such teams centrally as part of, for example, the strategy business unit or the CEO's office can be a way to add weight to their opinion and foster the top-down implementation of circular innovation (Man4, Man8, Man9).

Interestingly, several interviewees suggested that it might be easier to pursue circular innovations among family-owned firms, which do not have to satisfy shareholders on a quarterly basis and can endure longer break-even periods (Con8, Man3). Even though currently stock-listed firms cannot change their form of ownership, they can learn endurance and persistence from family-owned companies to successfully implement circular innovations.

#### *4.3.3.6. Culture and climate*

On top of these rather tangible success factors, an innovation-friendly culture was frequently mentioned as a reason for the successful implementation of circular innovations. Examples of such innovation culture include a *willingness to take risks* (Con2) and a *patience* to allow circular innovations to develop (Man5). Similarly, also the *freedom to innovate and experiment*, which has already been listed above in section 4.3.3.4 (creativity and idea management), has something to do with culture and climate. An innovation management that actively ensures such freedom can create an innovative climate and corporate culture.

Employees are, of course, the cornerstone of any company's culture and climate, as they are the ones who ultimately influence the direction in which the culture develops. Therefore, it is interesting to see that several success factors were mentioned by the CE frontrunners with regard to employees or specific groups of employees. The most prominent of those was the *support of a key employee/promotor,* often in upper management, for implementing the circular innovations. In the examples given during the interviews, these were either individuals involved in R&D who, convinced by a circular technology, were dedicated enough to push it through to implementation (Con1, Con3, Man2) or top managers/company owners who became convinced of the idea to embark on a CE transition with their company (Man3, Con8). The role of these key employees or *promotors* in the success of CE implementation has previously been outlined and analyzed by Hansen and Schmitt (2020). The findings in this dissertation further underline the importance of such promotors for the success of circular innovations.

However, it is not only top-level employees that can make a difference for successful CE implementation. *Having the right people with the right capabilities in the correct positions* throughout the organization was identified as another critical factor for the success of circular innovations of the surveyed CE frontrunners (Con1, Con4). This is easier said than done, but it outlines the importance of good talent management for the development of innovation capabilities at the firm level. Interestingly, at least two interviewees have mentioned that implementing circular innovations and actively using them for employer branding purposes has been a way to attract skilled people to apply for positions within their companies (Man1, Man8). With labor shortages looming in many sectors in Germany, particularly in the construction industry (Ahlers & Quispe Villalobos, 2022), such pull factors for employees can become critical for business success.

A last aspect that interviewees reported to be essential during CE implementation is *involving employees* in the transformation towards circularity. This can help ensure their buy-in during the transformation process and, ideally, even encourage bottom-up innovations from the employees (Man1, Con4, Con9). Concretely, one sample company brought its employees together to define a vision for its future jointly. During this exchange, it was employees who pushed for more focus on sustainability (Con2). Another CE frontrunner experimented with rewarding employees for bottom-up suggestions, thereby signaling their voices are heard during the transformation process (Con9).

#### *4.3.3.7. Management of technology*

Management of technology, as an element of innovation capabilities in the framework of Lawson and Samson (2001), refers to a broad range of activities within firms. For example, *anchoring circularity in the innovation process* is one of the specific practices observed among CE frontrunners within this area (e.g., Man1, Con4, Con5). One interviewee explained: "With every raw material, every conversation we have, every new product we develop, we always have Cradle to Cradle viability in mind from the very outset" (Con4). Such a top-down decision can ensure that during the new product development (NPD) process, only materials that can be considered circular are selected, or that products precisely follow DfX criteria. For example, multiple interviewees from one firm confirmed that there are checklists in the company's innovation process and NPD process, which ensure that the remanufacturing business unit is always consulted (Man1, Man6, Man7). Hence, an active change to the innovation process might be necessary to ensure that circularity is considered a criterion for future innovations.

Another interviewee, notably from a large manufacturing company with sufficient resources to allow for such a measure, even explained that the company went so far as *to establish a second, parallel innovation process/innovation safe space* (Man4). The company decided to facilitate the development of circular concept products (compare section 4.3.3.1) in an environment that breaks with innovation traditions. This is an essential addition to the earlier argument about the importance of freedom to innovate and experiment (compare section 4.3.3.4), as it shows that for creativity and innovation to flourish, companies need to make an effort and facilitate change actively. In this specific example, this was done by creating a safe space that breaks with traditional, linear processes of how innovation had been done before.

A whole area of its own, which was touched upon by almost all interviewees when asked about successful innovation practices, is digitalization. Digitalization is understood to play a vital role in facilitating the implementation of circular innovations. In fact, not only has there been significant literature already on the role of digitalization for the CE (Antikainen et al., 2018; Liu et al., 2022), but this very own paper has already found evidence for the relevance of business analytics capabilities, an arguably related concept, for CE implementation (Table 19 & Table 20). During the interviews, the most commonly mentioned area of application for digitalization concerned *product passports* (Con2, Man1, Man2) and, in the case of the construction industry, also *business information modeling (BIM)* (Con1, Con3). These tools and applications can potentially assist DfX innovations significantly and also support CBMI, as they provide information about a product's material composition, history, and sometimes even instructions for its EOL treatment (Man2, Man4). Some interviewees have additionally mentioned that product passports can help them with the localization of products (Con2, Con10). Producers, especially in the construction industry, who are not in direct contact with end consumers may be unaware of where their products end up. Similarly, until recently, interviewees from the automotive industry had no way of tracking the location of their products after the point of sale (Man8). Implementing product passports or BIM can address these issues. Nonetheless, it is important to note that while the introduction of digital tools today is crucial to ensure material recovery in the future, they often cannot help with the material recovery of products built in the past.

Realizing the critical role of digitalization for the implementation of the CE, CE frontrunners within this study's sample have, from the perspective of technology management, responded by actively *conducting M&A activities in the area of digitalization* (Con10). Others have *established their own business units focusing on digitalization* (Con2). Some of them have done so despite their relatively small size in comparison to industry peers, hoping to stay at the forefront of technology and gain a technological advantage over their competition in the field of digitalization. Therefore, both organic and inorganic growth have been viable strategies for companies to expand their digitalization expertise. In light of the results of the structural model in chapter 3, which confirmed perceived business analytics capabilities to have a positive effect on perceived CE implementation (Table 20), the importance of investing into digitalization can only be emphasized.

#### 4.3.3.8. *Additional success factors*

The sections above outline specific practices along the seven elements of the innovation capability model by Lawson and Samson (2001) that have helped CE frontrunners implement circular innovations. However, two additional categories of such practices that emerged during the coding of the interview results, namely marketing & sales and collaboration, were not included among those seven elements. This dissertation wants to mention them on top of those in the original innovation capability model to present these novel findings to ambitious companies looking for tools to drive CE implementation.

*Marketing & sales:* Respondents in both industries reported significant differences in their marketing & sales activities for circular products compared to linear products. More specifically, they noted that since circular products, or in some cases even CBMs, are new, they are sometimes initially viewed with skepticism by customers. Therefore, it is even more important for producers to *be closely connected to customers and other actors down the value chain* than it is in the case of linear products. One interviewee explained: "Thanks to our sales network, our contacts, and our proximity to customers, it is easy to bring such an innovation to the market" (Con2).

On the sales side, these efforts go as far as *educating customers in the area of CE* (Con4, Con8) or even *lobbying for changes* in procurement policies of public entities, in the case of the construction industry (Con4). On the marketing side, companies have stated that offering circular products or business models allows them to advertise products differently. Interviewees reported that they are *actively promoting circular innovations* from their position as frontrunners. Applying this practice, they benefit from increasing customer demands for circular products and the fact that the products can help customers fulfill ESG regulations, which are being introduced more and more on an EU level (Con3, Man2, Man3, Con8). All of this connects back to the quantitative study in chapter 3 and confirms its findings – CEI has the potential to influence brand reputation and also competitiveness positively (compare Table 19 & Table 20).

*Collaboration:* Another category that emerged during the coding of the interview results is collaboration. Practically all respondents agreed that the immense transformation that individual companies, as well as the economy as a whole, will have to undergo on their way to a CE will only be possible through collaboration. CE frontrunners in the construction and manufacturing industry have named different forms of collaboration that have helped them implement circular innovations. Firstly, *collaboration with start-ups,* especially in digitalization (Con9, Con10) and technology development (Man8), was found to be a way for firms to overcome barriers in these areas. Secondly, in many cases, *collaboration with universities or other research institutions* has proven to help with the implementation of circular innovations, especially among firms in the manufacturing industry. This can include collaboration focusing on technical aspects, such as the material composition of products or EOL treatment (Man1, Man3, Man8), but also the conceptualization of new CBMs (Man10, Man11).

CE frontrunners have benefited significantly from these two forms of collaboration with regard to overcoming firm-level barriers. However, some meso- and macro-level barriers also require *participation and collaboration in interest groups and industry associations*. An example where such collaboration is both necessary and a significant opportunity is the standardization of DfX for products and product parts across competing firms to improve EOL treatability (Man4, Con8). Standardization of data formats and reporting is another topic for which CE frontrunners have highlighted the importance of collaborating in groups/alliances (Man8, Con10).

Collaborations can also be a powerful way for firms to advertise new, disruptive, circular products. In this context, one interviewee went as far as to say: "This is the first time in my history in the market that I say: let's come together and unite with the others (…) and not compete anymore, but it's about preventing plastic (…), substituting it with [the circular product], and creating something new. So that is the interesting thing about the circular economy (…)" (Con3). Such collaborations can be a powerful way for SMEs or start-ups that are introducing circular innovations to challenge MNCs and their dominant market positions. Examples of intra-industry collaborations in general are the European Battery Alliance (EBA) in the manufacturing industry, the German Sustainable Building Council (DGNB), or the Madaster network, an online platform to register materials in new construction projects (Madaster Germany GmbH, 2023).

Two additional types of collaboration were mentioned by respondents, which related to collaboration with other actors along the value chain, the first of them being *collaboration with suppliers.* Some interviewees reported that they had significantly changed their collaboration with suppliers, intensifying cooperation in terms of material innovation or other technological innovations (Con2, Man2). With regards to new circular materials, one interviewee nicely summarized: “Just throwing them [the material requirements] over the fence and letting them [the suppliers] do it no longer works in this form. You need much, much closer cooperation” (Man2).

Other respondents reported *increased collaboration with recyclers and other EOL treatment companies,* i.e., actors further down the value chain. An example was the establishment of upstream CBMs, as producers looking to launch such CBMs typically need partners to provide collection points for products at the EOL (Con6, Man8). Similarly, it is in the recyclers’ interest that producers find ways to increase the share of customers, especially in the automotive industry, that bring or send their products to recycling facilities (Man8). An interesting approach in this context is using existing dealer networks, which had traditionally only been used in the linear business model, to implement reverse supply chains in both industries (Con8, Man5).

Interviewees have almost unanimously identified governmental institutions and regulations, or their absence, as obstacles to a faster transition to a CE. Nevertheless, some have pointed out how important *collaboration with governments and regulatory institutions* can be at the same time. For that reason, despite the legal and regulatory barriers, CE frontrunners are actively working to convince these institutions of CE technologies and solutions. This includes lobbying for regulatory changes (Man3) and participating in publicly funded research projects (Con1, Man8).

Table 25 summarizes the key activities for implementing circular innovations identified in the previous sections along the seven elements of innovation capabilities and the two additional categories of marketing & sales and collaboration.

**Table 25: Overview of successful activities along the elements of innovation capabilities**

| Category | Activities & practices | Evidence from the interviews |
|---|---|---|
| **Vision and strategy** | Taking a long-term perspective and develop a long-term strategy | Con9, Man4 |
| | Anchoring CE centrally in the firm’s strategy | Con3, Con5, Con8 |
| | Anchoring sustainability/circularity in the companies’ vision or mission statement | Con2, Con4, Man3, Man5 |
| | Experimenting, developing concept products, and testing in small sample sizes | Con9, Man2, Man8 |
| | Ensuring sufficient financing | Con1, Con2, Man2 |

| | | |
|---|---|---|
| **Harnessing the competence base** | Effectively harvesting and incorporating learnings from circular innovations | Con4, Man8, Man9 |
| **Organizational intelligence** | Active market research and analyzing the competitive landscape | Con1, Con2 |
| | Screening universities and start-ups for circular innovations | Man8 |
| | Setting up of a future-oriented radar to anticipate trends | Con5, Con9, Man5 |
| | Screening the legal environment and anticipating upcoming laws and quotas | Con6, Man2, Man4, Man8, Man9 |
| **Creativity and idea management** | Freedom to innovate and experiment | Con2, Con9, Man2 |
| | Introducing a frugal mindset in innovation | Con3, Man2 |
| | Dedicated training program for innovation capabilities | Con9 |
| | Establishing a dedicated innovation unit | Man8 |
| **Organizational structure and systems** | Connecting business functions and breaking down silos | Con2, Con5, Man1 |
| | Enforcing flat hierarchies | Con2, Con6, Man2 |
| | Involving business units dealing with product take-back in product innovation | Man1, Man8 |
| | Establishing dedicated teams/programs with a CE/sustainability focus and integrating them effectively with existing business functions and processes | Con5, Man4, Man6 |
| **Culture and climate** | Willingness to take risks | Con2 |
| | Patience | Man5 |
| | Support of a key employee/promotor, often in upper management, for the implementation of the circular innovations | Con1, Con3, Man3 |
| | Having the right people with the right capabilities in the correct positions | Con1, Con4, Man1, Man8 |
| | Involving employees | Con4, Con9, Man1 |
| **Management of technology** | Anchoring circularity in the innovation process | Con4, Con5, Man1 |
| | Establishing a 2nd, parallel innovation process/innovation safe space | Man4, Man8 |
| | Introducing product passports and Business Information Modeling (BIM) | Con2, Con10, Man2, Man4 |
| | Conducting M&A activities in the area of digitalization | Con10 |
| | Establishing own business units focusing on digitalization | Con2 |
| **Marketing & sales** | Being closely connected to customers and other actors further down the value chain | Con2 |
| | Educating customers in the area of CE | Con4, Con8 |
| | Lobbying for changes in e.g., procurement policies of public entities | Con4 |
| | Actively promoting circular innovations | Con3, Con8, Man2, Man3 |
| **Collaboration** | Collaborating with start-ups | Con9, Con10, Man8 |
| | Collaborating with universities or other research institutions | Man3, Man8, Man10, Man11 |
| | Participating and collaborating in interest groups and industry associations | Con3, Con8, Con10, Man4, Man8 |
| | Collaborating with suppliers | Con2, Man2, Man9 |
| | Closely collaborating with recyclers and other EOL treatment companies | Con6, Con8, Man5, Man8 |
| | Collaborating with governments and regulatory institutions | Con1, Man3, Man8 |

## 4.4. Summary of the qualitative study

The qualitative study has been conducted to answer the overarching research question (RQ 2):

> *How can firms in the construction and manufacturing industries leverage innovation for the implementation of the CE in practice?*

For this purpose, three sub-research questions were designed and answered through expert interviews with CE frontrunners among producers in the construction and manufacturing industry in Germany.

> *RQ 2.1: Which kind of circular innovations have been pursued by CE frontrunner firms in the construction and manufacturing industry?*
>
> *RQ 2.2: How can firms in these industries effectively decide which circular innovations to pursue?*
>
> *RQ 2.3: What are the drivers of innovation capabilities that can assist firms in implementing circular innovations?*

RQ 2.1 has helped to give an overview of the types of circular innovations that can be relevant for firms in the construction and manufacturing industries. Clustering the findings from the interviews, five types of circular innovations were identified and described: production process innovation, material innovation, DfX innovation, upstream CBMI, and downstream CBMI (Figure 19). This overview is the basis for addressing the overarching RQ 2.

Subsequently, RQ 2.2 aspired to explore how firms can effectively navigate the different circular innovations and decide which of them to implement. The interviews revealed that CE frontrunners consider multiple dimensions when assessing whether or not to implement circular innovations. These dimensions include an innovation's potential to generate a) monetary value, b) non-monetary business value, c) environmental and societal value, and d) its potential to enhance overall circularity. A framework has been developed to summarize these insights and provide concrete recommendations for firms facing the decision which circular innovations to implement (Figure 22 and Figure 23).

Finally, RQ 2.3 sought to address the gap in the literature regarding concrete innovation capabilities and practices on the company level that can help implement circular innovations successfully. The innovation capability model (Lawson & Samson, 2001) was used to structure the various activities identified among the CE frontrunners into the seven categories of “vision and strategy, harnessing the competence base, organizational intelligence, creativity and idea management, organizational structure and systems, culture and climate, and management of technology” (Lawson & Samson, 2001, p. 388). Two additional categories, marketing & sales and collaboration, have been developed to provide as comprehensive an overview as possible of the practices that have helped CE frontrunners to implement circular innovations.

Tying this back to the overarching RQ 2, the findings confirm innovation’s key role in implementing the CE. The radical changes needed to fully close material loops and eliminate waste are impossible without innovation. Companies in the construction and manufacturing industries can implement different kinds of circular innovation to contribute to overall circularity, each requiring a different level of effort and each with different effects, both for the firms themselves as well as for the CE (Figure 19). Choosing which circular innovation(s) to implement is not trivial, but firms at the beginning of their transition to becoming more circular can learn from the insights of CE frontrunners and apply the subsequently developed framework for their own decision-making (Figure 22). The findings show that the decision to implement circular innovations, other than a decision about linear innovations, typically relies on additional dimensions, not just the assessment of monetary value creation. Lastly, concrete innovation activities and practices were identified that can contribute to the successful implementation of circular innovations. While specific capabilities were found to be equally relevant in a linear context, the findings showed that to implement the CE successfully, firms in the construction and manufacturing industry must adapt their existing innovation capabilities or even develop new ones (Figure 25). In summary, section 4.2 should provide companies with detailed yet practical insights on how to leverage innovation for a transition to a CE.

### 4.5. Potential limitations of the qualitative study

The most apparent limitation of the qualitative study is that it focused on only one of the two constructs that were found to be significant in the quantitative survey, that of ICA, while it does not further examine the role of BAC for CEI. The reasoning behind this decision has been explained in the introduction of chapter 4, but ultimately, the relationship between BAC and CEI still needs to be explored at a comparative level of detail, as ICA has been researched in this dissertation.

This qualitative study has identified successful approaches to accelerate the implementation of the CE at the firm level through innovation. Semi-structured interviews with 22 experts of CE frontrunner firms were chosen as a method. This research design allowed for exploratory research across a wide range of companies, leading to insights into very different activities that each company had introduced or followed to ensure the success of their circular innovations. The findings of this dissertation provide a level of concreteness on innovation activities on a firm level that, to the author's knowledge, has not been presented in the literature before. However, this method naturally limits the depth at which individual innovation activities could be explored. Expanding the results of this study, future research could conduct individual case studies among similar frontrunner companies to go into even more detail about these innovation activities. Hansen and Schmitt (2020) have made such a contribution with their research on the role of promotors. Still, as Table 25 shows, there are many innovation activities other than the involvement of promotors that additional case studies could explore in further detail.

Lastly, interviews were conducted with firms considered *CE frontrunners* in their respective field. To ensure comparability and objectivity in the selection, the initial goal was to conduct only interviews among those firms that had obtained C2C certifications, acknowledging the high requirements for such a certification. However, given that few firms, especially in the manufacturing sector, have obtained C2C certifications for their products so far, other selection criteria had to be applied (Table 23). Interview partners were still screened vigorously, but a future study focusing exclusively on firms with C2C-certified products could ensure even higher comparability among the sample. This will hopefully become possible in the near future as the number of companies with C2C-certified products in the two industries of interest will increase.

# 5. Discussion and implications for management and research

This dissertation has examined the role of innovation for the implementation of the CE in the construction and manufacturing industry. First, a quantitative study has focused on the first research question:

> *RQ 1: How do innovation – and business analytics capabilities assist firms in the construction and manufacturing industries with CE implementation, and how does CE implementation impact firm performance?*

Second, a qualitative study built upon the findings of the quantitative PLS-SEM study and answered the question:

> *RQ 2: How can firms in the construction and manufacturing industries leverage innovation for the implementation of the CE in practice?*

In this discussion chapter, sections 5.1 and 5.2 discuss the main findings concerning these two research questions. Section 5.1 focuses on discussing the findings of the quantitative study before section 5.2 turns toward the findings of the qualitative study. However, among the findings that emerged from both the qualitative and quantitative studies, there are two additional thematic areas that, although not directly related to either of the two research questions, also merit discussion. They are both considered important enough, especially with regard to the goal of advancing the research field of CE implementation, that they, too, will be discussed in this chapter.

One of the two thematic fields concerns the role of the government in encouraging circular innovations. As governments set the framework conditions for the implementation of CE innovations at the company level, there is a need for at least a short section debating their role. Section 5.3 will give space to the role of governments and discuss it in connection to the relevant literature. The expansion or adaptation of the business model along the value chain is another thematic field that requires analysis. It was observed among several CE frontrunners and will be discussed in section 5.4.

## 5.1. Discussing the findings of the quantitative study

A first brief discussion of the results of the quantitative study has already been presented in chapter 3.11 to frame the results and set the scene for the qualitative study. The following paragraphs will pick this discussion up, expand it, and connect it to various other streams of literature to provide a detailed analysis of the academic and managerial implications of the results of the quantitative study.

### 5.1.1. The relationship between CE implementation and firm performance

One of the two most important findings of the PLS-SEM analysis is that it confirms the path dependency between CE implementation (CEI) and firm performance (PER). This insight is extremely valuable for both researchers and managers, as the debate about the effect of the CE on company performance has intensified in recent years. Various studies focusing on barriers to CE implementation have identified uncertain financial return (de Jesus & Mendonça, 2018; Guldmann & Huulgaard, 2020) and doubts about profitability in the CE (Ormazabal et al., 2018) across industries. Some of these studies also focused on the construction industry specifically (K. T. Adams et al., 2017). Therefore, it is crucial that this dissertation is able to confirm previous quantitative research examining the role between CEI and firm performance (Khan et al., 2020; Kristoffersen et al., 2021a) and shows that this relationship is also significant and positive for the construction and manufacturing industries in Germany. This is all the more important in light of the ever-increasing pressure to implement the CE in Europe and Germany and the criticism that the construction and manufacturing industries have received for lagging behind in the implementation of the CE (K. T. Adams et al., 2017; Kristoffersen et al., 2020).

Taking a closer look at the results of the PLS-SEM analysis, all of the four latent variables of the performance construct are statistically significant except for financial performance (PER-F) (p-value = 0.649) (Table 16). Khan et al. (2020) already observed in their quantitative assessment of the effect of CEI on firm performance that “financial performance was least improved compared to environmental performance, competitiveness, and corporate reputation” (Khan et al., 2020, p. 3029). However, they still found that CEI improved financial performance, alongside its positive effect on corporate reputation, competitiveness, and environmental performance (Khan et al., 2020). This is slightly different from the results in this dissertation, which does not find the LOC of financial performance to be significant.

As firms are naturally very concerned with their financial performance, this is an important aspect that will require attention in future research. Especially for publicly traded firms, which must report to their shareholders on a quarterly basis, it will be crucial that sooner or later, they can also expect a monetary benefit from implementing circular innovations. This becomes even clearer from the insights that the qualitative study provides into the decision-making process of CE frontrunners, who, despite also weighing in other factors, still consider monetary value as one of the most important dimensions when assessing whether or not they should implement circular innovations (section 4.3.2).

At the same time, the fact that the structural model (Figure 18) does not find financial performance (PER-F) to be significant might not be as dramatic as one might think at first glance. As already explained in section 2.3, truly committing to a CE means innovating with regard to products (Bocken et al., 2016), processes (de Jesus et al., 2021), or even business models (Lieder & Rashid, 2016). Section 4.3.1 further illustrated the different types of innovation encountered among CE frontrunners in the construction and manufacturing industries. All of these innovation efforts require investments from the firms implementing CE (Hart et al., 2019; Kirchherr et al., 2018; Kumar et al., 2019). To name just a few examples, these investments can include investments into R&D, the establishment of reverse logistics systems (Hart et al., 2019), new technologies (Kumar et al., 2019), but also investments into the whole supply chain (Bilal et al., 2020). Therefore, a feasible explanation for the non-significance of financial performance (PER-F) in the structural model could be that CE innovations implemented among the surveyed firms have not yet reached a financial break-even point. This argument is supported by Khan et al. (2020), who state that "return on investments takes time and depends on various factors too" (Khan et al., 2020, p. 3029).

The fact that the other latent variables of the performance construct (PER), such as competitiveness (PER-CO), are all significant (p-value = 0.000) suggests that firms do generate a competitive advantage through CEI. Such a competitive advantage can translate into a financial impact in the future. The interviews with CE frontrunners give hope to this argument, as they have proven that even though significance might not have been observed in the PLS-SEM model, individual companies in both industries have already managed to generate financial benefits from the implementation of circular innovations (Man1, Con5).

In this context, a bridge can also be built to the ambidexterity literature. Most circular innovations, particularly those aiming to achieve DfX or CBMI, can be categorized as exploratory innovations, as they radically alter how firms operate and design their products. This is supported by the findings of Jakhar et al. (2018), who have proven that exploratory rather than exploitative innovation capabilities support CE implementation in the manufacturing industry. All of this relates back to financial performance, as innovation research has argued for many years that exploratory innovations “require a large amount of resources, which may pay off only in the long run” (Mueller et al., 2013, p. 1610). This could explain the current non-significance of the lower-order construct of financial performance in the structural model.

Furthermore, other researchers have argued that “organizational units operating in more dynamic environments increase their financial performance by pursuing exploratory innovations” (Jansen et al., 2006, p. 1670). Jansen et al. (2006) define those dynamic environments as “characterized by changes in technologies, variations in customer preferences, and fluctuations in product demand or supply of materials” (Jansen et al., 2006, p. 1664). The construction and manufacturing industries have been exposed to significant changes in the last years from events such as the COVID-19 pandemic and the Russian invasion of Ukraine, to name just a few (Wohlrabe et al., 2022). These changes increase the dynamics in both industries. Suppose the argument by Jansen et al. (2006) is correct, and exploratory innovation in dynamic environments does indeed lead to increased financial performance. In that case, this is another reason to believe that in the future and in an increasingly dynamic industrial environment, CEI will also have a positive effect on financial performance in both industries.

In summary, both the literature and the findings from the interviews give hope that the statistical relationship between CEI and PER-F will become significant in the future. Research will need to test whether these aspirations materialize and whether an effect of CE implementation on financial performance can ultimately be achieved not only among a selected group of CE frontrunners but among a wide range of companies. Only then can the circularity gap in the two industries be expected to close. As mentioned before, it will be in the interest of both academia and managers to monitor this development in the medium- and long term as it is naturally in every company’s interest to ultimately not only achieve a competitive advantage on its competition through CEI but to also materialize this in terms of financial performance.

Nevertheless, from a managerial perspective, the quantitative study in chapter 3 should provide firms in both industries with more than enough reasons to pursue CE implementation, given its significantly positive relationship to firm performance. In line with the previous discussion, if financial performance were to become significant in the medium or long term too, the incentive for companies to adopt circular innovations would only increase.

### 5.1.2. How business analytics- and innovation capabilities can help CE implementation

The second, and perhaps more important finding with regard to the overall objective of this dissertation is that both business analytics capabilities and innovation capabilities can influence CE implementation positively. While previous research has assessed the role of innovation capabilities (Jakhar et al., 2018) and business analytics capabilities (Kristoffersen et al., 2021a) for CE implementation separately, this study combines the two constructs in one model. To the author's knowledge, it is the first model to do so.

For managers, the recognition that there is a positive influence of both constructs (i.e., BAC and ICA) on CEI is crucial. It points companies towards practical solutions for tackling the immense challenge of transforming their business models. From the angle of academic implications, this confirms previous research focusing on the role of business analytics (e.g., Antikainen et al., 2018; Bressanelli et al., 2018; Kristoffersen et al., 2021; Liu et al., 2022) and innovation (e.g., Jakhar et al., 2018; Lieder & Rashid, 2016) for CE implementation. More generally, it also underlines the importance that researchers have attributed to the overall development of organizational capabilities for CE implementation (Castro-Lopez et al., 2023; Köhler et al., 2022).

The findings are also important for non-academic proponents of the CE, such as the Ellen MacArthur Foundation (EMF) or the European Commission. The EMF has advocated in multiple reports for the CE and has emphasized the role business analytics and innovation can play in its implementation (Ellen MacArthur Foundation, 2016, 2020a). The claims of the EMF, which have been based on selected examples from practice and case studies of CE frontrunners in many cases, are now further supported by the results of the quantitative, large-scale survey in this dissertation.

To summarize, the answer to RQ 1 is as follows: both innovation capabilities and business analytics capabilities can significantly assist companies in implementing the Circular Economy. Companies can also expect CE implementation to positively impact their firm's performance, especially in terms of competitiveness, corporate reputation, and environmental performance. However, the influence on financial performance has not been found to be significant at this stage.

## 5.2. Discussing the findings of the qualitative study – the role of innovation capabilities in the context of a CE

The managerial implications of the qualitative study presented in chapter 4 are quite clear. Managers who want to transform their organization into a more circular one and implement circular innovations will find both the decision framework (Figure 22) and the innovation activities (Table 25) helpful in this endeavor. These findings are derived from successful CE frontrunners and can hopefully be an inspiration for companies that are still in the early stages of their transformation.

Arising from the initial problem of the slow implementation of the CE and the ever-increasing pressure on companies, the aim of RQ 2 has been to identify how firms in the construction and manufacturing industries can leverage innovation to manage the transformation to a Circular Economy. To radically change products, processes, and business models for the CE, firms need to be innovative. Researchers have long understood that the acquisition of a specific set of capabilities can influence the success rate of creating "new products and processes, and respond to changing market circumstances" (Teece & Pisano, 1994, p. 541). Companies on the road to the CE also find themselves in a situation of changing market conditions. They too, need to demonstrate capabilities that can help them implement the CE. Therefore, it is more than sensible to consider the challenges of implementation against the background of the dynamic capabilities or innovation capabilities literature.

The qualitative study set out to identify the specific activities in place among CE frontrunners that have helped them to implement circular innovations based on the argument that "without an understanding of the specific activities underlying capabilities, study replication and knowledge development in the area is difficult" (Lawson & Samson, 2001, p. 380). Improving the specific activities, practices, and processes of each of the seven elements of innovation capability, as proposed in Lawson and Samson's (2001) model, can positively affect a company's overall innovation capability. In turn, this can have a positive impact on CEI, as demonstrated by this dissertation's structural model (Figure 13). Understanding this is crucial, as it breaks down the construct of innovation capabilities and emphasizes the importance of the specific activities and practices identified in section 4.3.3. Firms can enhance innovation capabilities by improving the individual elements that make up the construct. The concrete activities observed from CE frontrunners in the categories of, for example, organizational structure, organizational culture, etc. (Table 25) can be leveraged to achieve this. These provide managers with concrete levers for improvement to accelerate CE implementation.

The following paragraphs will examine the activities and practices identified among CE frontrunners in more detail and propose to cluster them into the three categories of *non-CE-specific activities and practices, CE-specific activities and practices*, and those in between, referred to here as *activities and practices with different weighing in a CE.* This categorization, together with a discussion of individual activities against the background of the innovation literature, will promote their implementation further.

*Non-CE-specific activities and practices*

If one compares the findings in Table 25 to those capabilities that Lawson and Samson's (2001) had originally discovered in their research to contribute to innovation in a linear economy, it is possible to quickly identify an overlap. Some capabilities have been identified among CE frontrunners that are equally essential for innovation success in a linear economy. An example of activities for which that is the case are *'enforcing flat hierarchies'* (Con2, Con6, Man2) in the area of organizational structure and systems or *'setting up a future-oriented radar to anticipate trends'* (Con5, Con9, Man5) in the area of organizational intelligence. Innovation researchers, and even those who do not describe themselves as such, might rightly point out that these practices do not exclusively support circular innovations but have previously been identified as supportive of linear innovations.

The positive influence of flat hierarchies on innovation, for example, has been argued for years, especially under linear economic circumstances. In particular, its positive impact on idea generation has been outlined in the past (Keum & See, 2017). Jansen et al. (2006) have also proven that centralization and more hierarchies negatively influence exploratory innovation. Similarly, '*setting up a future-oriented radar to anticipate trends'*, as it was termed here, is also not a practice that can claim to be successful only in a CE. Corporate foresight literature has previously proven the positive impact of foresight practices, including those concerned with perceiving, to identify trends and signals early (Rohrbeck & Kum, 2018). Once again, these findings were not discovered among CE frontrunners but under linear economic circumstances. '*Enforcing flat hierarchies'* and '*setting up a future-oriented radar to anticipate trends'* are, therefore, two activities that contribute to the success of innovation not only in the context of the Circular Economy.

But what does that mean for firms looking to transition to a CE? It can be good news that some capabilities, which were vital to the success of CE frontrunners, have previously also been found to be essential in a linear economy. In essence, this means that innovative firms with a linear business model will benefit if they have already implemented flat hierarchies today or if they have already set up a trend radar. It means that some of the capabilities that have helped them to innovate and to stay ahead in the linear economy can now also help them to implement a CBM or successfully introduce circular products.

*CE-specific activities and practices*

Conversely, there are also certain activities and practices mentioned by CE frontrunners that can indeed be classified as CE-specific, in other words, activities that even the most innovative firms will need to develop newly, as they were previously not relevant in linear business models. Potentially one of the best examples of this is *'introducing product passports and Business Information Modeling (BIM)'* in the area of management of technology. Tracking location, wear and tear, and material composition, particularly of complex products, such as those in the construction and manufacturing industries, is especially important in the CE (Antikainen et al., 2018; Ellen MacArthur Foundation, 2016). CE frontrunners have innovated product passports, BIM, and other digital tools to provide this information throughout their products' life cycle (Con2, Con10, Man2, Man4).

The introduction of *'product passports and Business Information Modeling (BIM)',* and in that sense the digital accompaniment of a product throughout its entire life cycle, has previously not been of the same importance for producers under linear economy circumstances. In a linear economy, producer responsibility often ends at the point of sale. Typically, any innovation concerned with a digital accompaniment of a product after the point of sale is not incentivized. In a CE, however, producer responsibility is extended, and as a result, even companies that were previously categorized as innovative will have to develop new applications and technologies to be able to meet the changing requirements (Kunz et al., 2018). This argument is supported by CE literature, which has identified some "digital functions applied in reverse supply chain that do not often exist in linear supply chain" (Liu et al., 2022, p. 2182). New capabilities are necessary to be able to successfully innovate and apply the new digital applications, such as product passports and BIM tools.

Another example of a CE-specific practice introduced by CE frontrunners can be summarized as *'involving business units dealing with product take-back in product innovation'* (Man1, Man8) in the area of organizational structure. This activity refers to the previously mentioned integration of the take-back department with the R&D department. Firms that have introduced CBMs and offer a take-back, repair, or even rental option suddenly find themselves with thousands of their own EOL products. Previously, in a linear business model, they had no access to them, as customers typically disposed of them after use. For companies, this means they suddenly have access to thousands of data points about, for example, actual customer usage patterns or their products' wear and tear throughout the life cycle (Man1). Firms with a linear business model typically need to conduct complex long-term tests to gather data on, for example, wear and tear. Alternatively, they need to conduct significant market research to identify customer use patterns. These efforts become redundant if circular firms can collect the same and even more accurate data from returned products, providing insight into actual customer usage patterns (Man1). However, harvesting the data and ensuring it is used to continuously improve the product, for example, by reacting to common wear and tear patterns, requires a smooth integration of the take-back department with the R&D department.

Of course, inter-departmental collaboration is not unheard of in firms with a linear business model either. For example, a large empirical study in Germany, which did not specifically focus on the CE, found evidence that "inter-departmental collaboration benefits process innovation outcomes but not the results of product innovation" (Cuijpers et al., 2011, p. 573). The contribution of this dissertation is, therefore, not the insight that inter-departmental collaboration can positively influence innovation but that firms innovating in the context of the CE need to embrace new forms of inter-departmental cooperation within companies to establish circular business models. These forms of collaboration, such as between the product take-back and R&D department, are CE-specific, as they are the result of products returning from CBMs. Therefore, companies need to develop new capabilities.

*Activities and practices with different weighing in a CE*

The sections above describe activities and practices that firms do not need to adapt in a CE context, as well as those that are CE-specific and need to be newly developed by firms committed to becoming circular. However, to suggest there are only these two categories would be an oversimplification. Many of the innovation activities identified in the qualitative study as crucial for the success of circular innovations (Table 25) fall somewhere between these two extremes. This will be illustrated by describing three examples in the following paragraphs. These examples show a third category of innovation capabilities needed for circular innovations – those with a different weight in a CE context. These capabilities do not have to be developed from scratch but must be adapted from how they previously supported linear innovations.

The first example to illustrate this category focuses on the capability to *'experiment, develop concept products, and test in small sample sizes'* (Con9, Man2, Man8). This is undoubtedly also key for innovation success in many companies still following a linear business model. Concept design is a core component of virtually every product design process, regardless of whether it is a circular or non-circular product (Ulrich & Eppinger, 2016). However, this dissertation argues that it carries a different weight in the context of the CE. Given the novelty of circular products or business models in the markets, as well as for the companies themselves, proving the feasibility of circular innovations has an entirely different weight. This may involve the first use of new circular raw materials, such as biodegradable materials or secondary raw materials, i.e., recyclate. It can also be about radically new business models, such as introducing a product-as-a-service business or leasing business model. It always takes a frontrunner to prove that the innovation works and can be successful. The frontrunner often has to convince not only customers but also internal stakeholders of the innovation. The task of persuading stakeholders can be more challenging for circular innovations than for linear ones. CE literature supports this, identifying a *difficulty to attain management support for circular products and business models* (Guldmann & Huulgaard, 2020; Kumar et al., 2019) and a still widespread *lack of consumer interest in circularity* (Circular Economy Initiative Deutschland (Ed.) et al., 2020; Kumar et al., 2019) as barriers to CE implementation. Another indicator of this is the importance that CE frontrunners attribute to the education of stakeholders across the value chain (Con4, Con8). This is why a successful pilot or initial concept product is crucial for circular innovations, even more than it already is for linear innovations. It demonstrates that although the same innovation capability is necessary in both circular and linear economies, it carries a different significance in the context of the CE.

The second example to further illustrate this category are the activities summarized in Table 25 under the element of *collaboration*. They include activities such as *collaborating with suppliers*, *collaborating with universities or other research institutions*, or *collaborating with recyclers and other EOL treatment companie*s. Once again, collaboration can also be essential for innovation success in a linear economy. Nevertheless, the interviewees were so clear about the new role of some collaborations that a detailed discussion of the theoretical implications of these insights becomes necessary at this point. Section 4.3.1.3 has highlighted the new collaborations that are required to ensure that DfX innovations do not only work in theory but also in practice. DfX innovations are just one example of collaboration in the CE being even more important than it already is in a linear economy. Other examples in which CE frontrunners in both industries have entered into new forms of collaboration and partnerships include collaboration with sales dealers to offer collection points for EOL products (Con8, Man5) or collaboration with start-ups to expand digitalization for the CE (Con9, Con10).

This finding from the qualitative study further confirms insights previously presented during the literature review on innovation and the CE (section 2.3). "Circular as compared to conventional innovation requires the intense collaboration of an extended actor set consisting of internal and external constituents" (Schmitt & Hansen, 2018, p. 27). Acknowledging the extended actor set, subsequent research has argued for a need to widen "the innovation perspective to include the ecosystem, next to a product or service and the business model" (Konietzko et al., 2020, p. 2). As collaboration intensifies and the set of actors expands, the demands on the capabilities required at the producer level change. Including the ecosystem and all the actors part of it in the innovation perspective increases the complexity that producers have to deal with in their innovation process (Figure 24). More actors and their interests have to be managed. This requires producers to expand existing collaboration capabilities or even develop new ones.

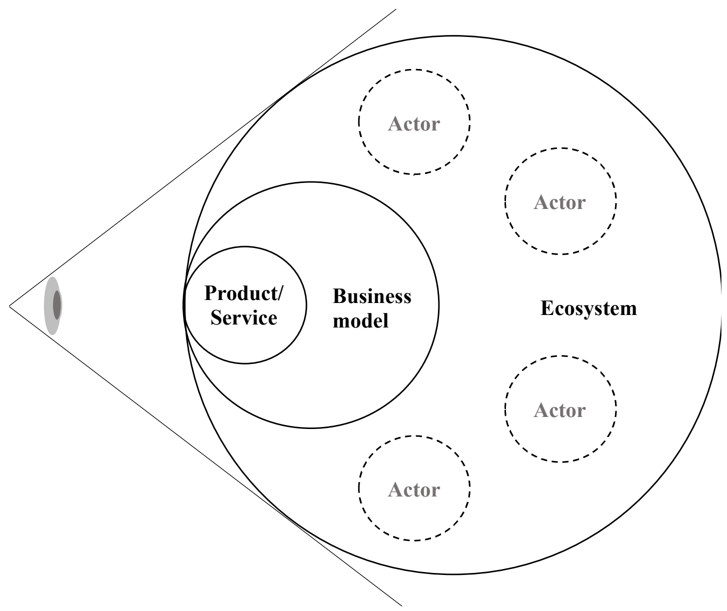



**Figure 24: Circular ecosystem framework**[31]

[31] Source: Konietzko et al. (2020, p. 2)

The value chain, particularly in the construction industry, is especially complex, as it includes additional actors, such as architects, structural engineers, developers, and carpenters (Figure 8). The resulting circular ecosystem relevant for any innovation is, therefore, equally more complex in the case of the construction industry. In turn, a more complex circular ecosystem requires even more advanced collaboration capabilities. Digital technologies, such as digital product passes, can be a way to facilitate collaboration, as they provide multiple actors in the ecosystem with access to data about, for example, the material composition of buildings (Konietzko et al., 2020, p. 2; Madaster Germany GmbH, 2023). At the same time, the use of these digital technologies also places new demands on producers' capabilities.

It can be summarized that an ability to collaborate successfully in a linear economy can be advantageous for producers. However, it is essential to note that collaboration in a CE context is different and sometimes more complicated. Therefore, companies need to adapt their capabilities and develop them further.

The third example that illustrates that some innovation capabilities have a different weight in the CE is the *'screening the legal environment and anticipating upcoming laws and quotas'* (e.g., Con6, Man2, Man4, Man9). Again, dealing with the legal environment is a common challenge for players operating in heavily regulated industries, such as the automotive industry or the production of components for the construction industry. However, the introduction of more and increasingly detailed laws and regulations to accelerate the transition to a CE in Germany and the EU is now confronting the players in these industries with new, additional requirements (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2020; Directive 2008/98/EC, 2008). This forces them to innovate products and sometimes even business models to comply. At the same time, the introduction of circular innovations, such as the development of products from recycled materials, is heavily regulated, too. In many cases, from a legal perspective, innovating circular products from recycled materials is significantly more complicated than innovating linear products from virgin materials (Con10, Man3). Therefore, also in this field, it is vital for companies to expand their capabilities to either anticipate regulatory requirements or to react appropriately to the increasingly complex regulations.

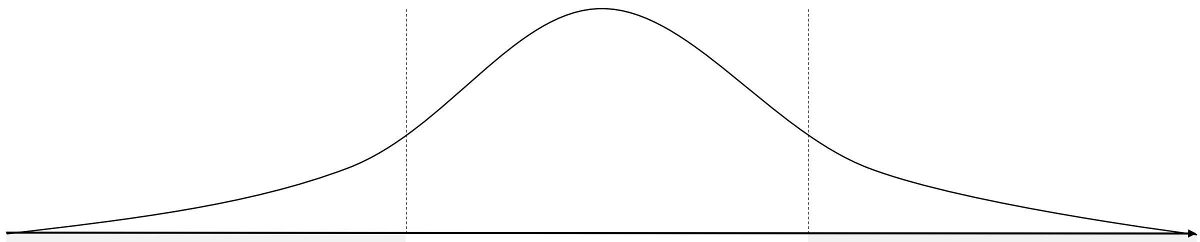
The three examples above highlight innovation capabilities companies need to expand on in addition to the capabilities that previously ensured success in a linear environment. In other words, these capabilities carry more weight in a CE and become more important for companies developing circular products or business models. While it is certainly true that the complexity of operating in a CE requires additional capabilities, there are also capabilities for which it could be argued that they carry less weight in a CE context. One specific example illustrating this is the activity of *learning from customers*. Together with learning from the competition, these are two aspects that, according to Lawson and Samson (2001), are the core of the pillar of *organizational intelligence* – one of the seven elements that constitute innovation capabilities.

Entire research fields, such as user innovation research (Von Hippel, 2005), have been focusing on the role of customers and consumers recognizing their importance for innovation. Somewhat surprisingly, however, few of the CE frontrunners in the interviews highlighted the importance of gaining knowledge from customers for the development of circular innovations. Only one interviewee specifically mentioned customer requests as a source for circular innovation (Con4). On the contrary, multiple respondents, especially from the construction industry, pointed out that the introduction of circular innovations required education of customers and consumers, instead of learning from them (Con3, Con8, Con9, Con10).

A potential explanation for this could be the lack of awareness and knowledge about CE among customers and consumers, as often criticized in CE literature (Grafström & Aasma, 2021; Kumar et al., 2019). The novelty of circular innovations and their radical nature can also be a reason why the interviewees have not stressed the customers' role in the innovation process. Circular innovations might be, at least at the moment, push rather than pull innovations. The fact that learning from customers was not mentioned as a success factor for circular innovations among CE frontrunners could lead to the belief that capabilities in that area are not as important for companies as they are in the context of linear innovations. This will need to be tested by future research since there is also literature providing evidence of the contrary, namely of the relevance of user innovation in the context of sustainability (Peuckert & Kern, 2023). Either way, *learning from customers* is another example of a capability that this dissertation's findings suggest carries a different weight in the context of the CE.

The core message of section 5.2 can be summarized as follows: Although some capabilities can certainly support innovation independently of CE and others are in some way newly required in the CE context, most of the innovation activities and practices listed in Table 25 fall somewhere between the two extremes and are neither unique to the CE context nor are they 100% overlapping with those activities and practices relevant to linear innovation. The division into the three categories is a suggestion, and Figure 25 is primarily illustrative. For this reason, only selected examples from the list of innovation activities (Table 25) were chosen to illustrate the three categories.

This dissertation encourages future research to develop further and empirically investigate the idea of CE specificity of innovation capabilities and, if necessary, to expand or challenge the categories proposed here. What is most important to recognize is that many of the identified innovation activities and practices, although they are also relevant in the linear economy, as described here several times, carry a different weight in a circular context or need to be carried out slightly differently.



| **Non-CE-specific innovation activities and practices** | **Partly CE-specific innovation activities and practices (some adjustments necessary)** | **CE-specific innovation activities and practices** |
|---|---|---|
| Examples:<br>• Introduction of flat hierarchies<br>• Setting up a future-oriented radar to anticipate trends | Examples:<br>• Experimenting, developing concept products, and testing in small sample sizes<br>• Collaborating with suppliers<br>• Collaborating with recyclers and other EOL treatment companies | Examples:<br>• Introduction of product passports & Business Information Modeling (BIM)<br>• Involving business units dealing with product take-back in product innovation |

**Figure 25: Illustrating CE-specificity of innovation capabilities**[32]

The insight that many innovation capabilities differ in the context of circular innovations compared to how they have previously assisted linear innovations is crucial. It means that even firms that have innovated successfully in a linear economy must adapt at least some of their innovation capabilities or develop them further. Failure to do so could put even innovative firms at risk of not successfully implementing the CE. Conversely, this also means that

[32] Source: Author's illustration

companies that now understand which new or modified innovation capabilities are needed in a CE can have an immense advantage in the implementation of circular innovations.

## 5.3. The role of the government in encouraging circular innovations

This dissertation has chosen to examine the implementation of the CE from the perspective of individual firms. Nonetheless, one cannot ignore the role of the government or other regulatory bodies, given their importance for the success of the overall transitions from a linear to a circular economic system. Government bodies define the framework conditions for any innovation, can exert pressure on companies through tighter regulations, and can encourage companies to innovate by providing the right incentives.

Sections 4.3.1.1 to 4.3.1.4 describe different categories of circular innovations that CE frontrunners have already implemented in the construction and manufacturing industries. Section 4.3.2 has developed a framework that can help firms looking to implement circular innovations with decision-making (Figure 22). It shows that most companies will naturally consider implementing only those innovations from which they can expect business value in return, whether monetary or non-monetary. The interviews have revealed many cases of circular innovations for which this is already the case, i.e., circular innovations, that have been successfully implemented because they bring significant benefits to producers in the construction and manufacturing industries. However, the interviews also revealed that even CE frontrunner companies have in some cases not adopted circular innovations for all of their products, but only for selected ones.

For many individual companies, this is simply a business decision. One interviewee summarized this very nicely: “In the meantime, [the use of circular materials] is more expensive, which means that in ongoing projects (...) we do not consider them. That is if at all, only considered for new products” (Man2). In other words, there are motivated companies that are in favor of circular innovations in principle, but they still do not implement them. This is hardly surprising, especially in light of the insights into the decision-making process among CE frontrunners. Section 4.3.2 has shown that even for CE frontrunners, an innovation’s potential to generate monetary value remains one of the most important criteria.

However, given the clearly stated intent of the European Commission (Directive 2008/98/EC, 2008; European Commission, 2015) and the German government (Circular Economy Initiative Deutschland (Ed.) et al., 2021; Kreislaufwirtschaftsgesetz (KrWG), 2012) to accelerate the transition to the CE on a larger scale, any such decision by an individual firm not to implement a circular innovation is a missed opportunity. One would expect it to be in the government's interest to ensure that circular innovations, for which the ROI for companies is close to the break-even point, are implemented and not discarded. As government bodies cannot implement circular innovations themselves, this means they need to provide the right conditions for companies so that more and more circular innovations pass through the decision-making framework (Figure 22) – in other words, widening the funnel for circular innovations to make their implementation more attractive for individual firms (Figure 23).

Significant research has already gone into identifying the government's role in supporting the transition to a Circular Economy. Commonly listed instruments for governments to make circular innovations more attractive to individual companies include the installation of a CE-favorable tax system, the introduction of CE-specific definition and standards, the provision of a comprehensive and favorable legal system, the installation of an adequate recycling infrastructure, and among others the support for education and knowledge generation (Circular Economy Initiative Deutschland (Ed.) et al., 2021; Löw et al., 2023). Another commonly identified leaver to increase demand for circular products and thereby help producers reach economies of scale and the break-even point for their innovations can be to adapt public procurement guidelines to favor circular products (Grafström & Aasma, 2021; Guldmann & Huulgaard, 2020).

This interpretation of the role of government bodies and regulators as actors whose primary task is to change the conditions to make it easier for companies to implement circular innovation resonates with the wishes and demands that interviewees in the qualitative study have formulated on multiple occasions. One interviewee explained how the company is trying actively to "lobby a lot with politicians, associations, and suppliers to find ways to get products back from demolition sites in a sorted state" (Con2). Similarly, another interviewee argued for a $CO_2$ price and resource consumption taxes to reduce overall resource use, later arguing that "without a change of the system steered by policymakers, there is no way to escape from this big thing [the linear economy]" (Man4).

Even if governments and political recommendations were not the focus of this research, the role they can have in the success of circular innovations cannot be neglected. It is not surprising that, as the examples above show, producers, who can be considered CE frontrunners, lobby for such policies, as they would help them implement circular innovations and make their lives easier. At the same time, one would expect opponents of interventionist governmental policies to argue against measures, such as favorable tax rates for circular products or changes in public procurement guidelines in favor of circular products. However, from a CE perspective and especially given the current low global circularity rates (Circle Economy, 2024), the world cannot afford to let those companies daring to pioneer circular innovations fail. Although this dissertation has placed a clear focus on the corporate perspective and has highlighted the levers companies can pull to implement circular innovations successfully, the importance of governments and regulatory authorities for these innovations must be emphasized. Without support from the legal framework and regulatory bodies, or at least the removal of barriers in this area (Grafström & Aasma, 2021; Hart et al., 2019; Kumar et al., 2019), it will not become any easier to implement circular innovations, which often face enough headwinds anyway.

## 5.4. Business model expansion along the value chain – the right thing to do in a CE?

The last thematic area requiring discussion concerns business model innovation in a CE. An important insight from this dissertation has been that depending on each individual firm's circumstances, a different type of circular innovation might be more sensible than another (compare section 4.3.1). For some firms, it may make sense to establish an upstream CBMI, while other firms can contribute to circularity just as much by 'only' implementing a material innovation. Each company looking to implement circular innovations goes through an individual decision-making process. Figure 22 has provided a framework for this decision-making process. Lichtenthäler and Neligan (2023) correctly argue that "the decision, whether to implement the [circular] strategies holistically or to specialize in individual circular strategies depends on the sector, the company's activity as well as the depth of value creation and the company's position in the value chain" (Lichtenthäler & Neligan, 2023, pp. 80–81). In this respect, the decision-making process for the implementation of circular innovations hardly differs from that in a linear economic system. Following a similar line of argumentation, Porter and Kramer (2006) have previously explained how "every company operates within a competitive context, which significantly affects its ability to carry out its strategy, especially in the long run" (Porter & Kramer, 2006, p. 9).

Bearing these underlying assumptions in mind, it is worth looking at which innovations the CE frontrunners implemented in the end. In both industries, companies have reported many examples of business model innovation, expanding the existing business model along the value chain (compare section 4.3.1.4). One example of this has been upstream CBM innovation

(Con8, Con9, Con10, Man1, Man4, Man8), which has become a core part of some CE frontrunners' (circular) strategy. Motivated by a lack of an adequate recycling infrastructure (Con10), the wish to reduce supply chain dependency (Con8), the desire to retain ownership of valuable materials (e.g., Man3), or the hope to enter a profitable business segment (Con9), some of the CE frontrunners have decided to build recycling factories of their own.

Each firm has to decide for itself which circular innovations it implements and which it chooses not to implement. However, it needs to be discussed that expanding the business model along the value chain, e.g., by setting up its own recycling infrastructure or by introducing a refurbishment business model (Con8, Man1), contradicts long-standing economic theory that argues for the concept of comparative advantage and calls for specialization rather than diversification (Ricardo, 1817). One of the most basic economic theories, the theory of the *division of labor*, follows the same line of thought, suggesting it is ultimately a division of tasks that leads to economic progress instead of one actor performing multiple tasks simultaneously (Smith, 1998). In management theory, this argumentation most famously resulted in the concepts of *core competencies* and *core products* (Prahalad & Hamel, 1990). Translating these concepts to the CE context would mean that to ensure the highest overall value creation at a national level, producers should focus on production, and recyclers should take care of recycling, as this is each actor's field of expertise.

Interestingly, one of the interviewees argued similarly, favoring a division of labor, and highlighting the importance of third parties. The interviewee from the manufacturing industry stated that producers can and should not be the ones closing the material circles (Man4). From this statement, one can see that there is no consensus among CE frontrunners. Some interviewees reported their companies were actively introducing circular business models, expanding into segments of the value chain in which they previously had not operated. In contrast, others explained that they had deliberately chosen not to follow such a strategy.

The interviewed frontrunners from the construction and manufacturing industries are not the only companies having to decide whether or not to innovate CBMs and, as a consequence, expand their activities into new segments of the value chain. Two concrete examples of major players in the German fast-moving consumer goods (FMCG) industry may help to illustrate this point further. Each of the two companies made a different decision about CBM innovation. One of the two is Werner & Mertz. The company is considered a pioneer of circular innovation, offering many C2C-certified products, and is driving the CE in the FMCG sector. Nevertheless, Werner & Mertz has never established its own reverse logistics systems or offered any other CBMs. Instead, they have focused on material innovation and, at the same time, invested heavily in innovation in the area of DfR to make products easy to recycle. Today, Werner & Mertz is almost exclusively using mono-materials and heavily relies on recycled materials from MSW for the packaging of their products (Werner & Mertz, 2017; World Packaging Organization, 2023). The company has chosen to focus on its core competencies and core products and has decided not to expand its business model along the value chain.

Lidl stands in contrast. The German retailer, which also offers an extensive portfolio of its own private label products, has chosen a path of vertical integration and has, like some of the CE frontrunners in the construction and manufacturing industry, heavily invested into establishing its own recycling infrastructure. In 2018, for example, the Schwarz Group, to which Lidl belongs, acquired Tönsmeier, Germany's fifth-largest recycling company (Bünder & Scharrenbroch, 2018). Under the principles of the division of labor, such a step seems atypical at first, but from Lidl's perspective, it was based on concrete strategic considerations.

At this point, it is worth noting that the proponents of diversification and division of labor are, of course, not unchallenged. Some authors also contradict the arguments of Prahalad and Hamel (1990) and argue that under certain circumstances, vertical integration may be more beneficial than focusing solely on core competencies and core products. Proponents of a vertical integration strategy, most notably Chandler (1977), have, for example, described the advantages of vertical integration of manufacturers into retailing. This confirms that similar to CE frontrunners, researchers also do not unanimously favor one strategy over the other.

Turning back to the construction and manufacturing industries in Germany, findings from this dissertation have shown that producers who are looking to implement the CE find themselves at a crossroads. In the concrete example of upstream CBMI, producers are facing a lack of adequate EOL treatment infrastructure (Circular Economy Initiative Deutschland (Ed.) et al., 2020; Kumar et al., 2019). As a result, some are turning to establishing their own infrastructure, while others trust market mechanisms and third-party waste treatment companies to address the problem. This dissertation does not attempt to suggest which of the two strategies is right or wrong, referring once again to the argument that each individual company's circumstances influence its strategic decision-making process (Lichtenthäler & Neligan, 2023, pp. 80–81). Rather, it is important to note that traditional producers in both industries are expanding their business model along the value chain on their path toward a CE. This is due to imperfections in existing EOL infrastructure or the hope to exploit new business opportunities. Another important element of the truth is that in most cases, vertical integration is only an option for companies with the size of MNCs. Without strong partnerships, SMEs will never be able to close entire material flows themselves or establish recycling facilities and the associated supply chains. Ultimately, also this discussion comes back to the relevance of collaboration and partnerships (compare section 5.2).

From a CE perspective, there is one additional aspect to this discussion. As has been pointed out multiple times, privately owned producers are primarily interested in closing those material cycles for which they have a financial or other business incentive. In the automotive industry, battery cycles have been named as a prominent example of this (Man4), but there are also examples from the construction industry. From an individual company's perspective, it makes sense to focus on those materials of value, i.e., those that can either be sold for profit or replace pricey virgin materials in future products. However, this raises the question of whether this form of 'cherry-picking' certain high-value materials or components for material recovery while de-prioritizing the treatment of others might actually end up reducing overall material recovery rates in the end, as it decreases the value of the remaining 'waste'.

In the specific example of an EV, it could be argued that if the battery, i.e., one of the most valuable items at the EOL, is returned to the OEMs, this reduces the incentive for private recycling firms to recover the remaining materials from the products. This is due to the fact that these companies naturally have an interest in treating high-value waste primarily. One interviewee described this new dynamic between producers and recycling firms. In the past, the whole product would pass over into the hands of the recycler. Today, as a result of circular business model innovations on the side of producers, there is competition for specific components and materials (Man8). In a scenario where only selected high-value components or materials are treated at the EOL, either state-owned EOL treatment companies would have to treat the remaining 'low-value waste', or governments would have to require producers to treat the entire EOL product.

In summary, as previously stated, it is not possible from a managerial standpoint to conclude which strategy is optimal for companies in the construction and manufacturing industries.

Depending on the industry context and company-specific situation, it may be advisable to focus on core products or to expand along the value chain. Neither strategy can guarantee a competitive advantage.

For research, however, these findings suggest significant implications. Future research needs to examine the reasons why companies in a CE context deviate, at least in part, from long-standing scientific recommendations and do not focus on core products and competencies (Prahalad & Hamel, 1990) but instead, for example, set up their own recycling plants and reverse logistics processes. This dissertation has found that CE frontrunners have various reasons for introducing CBMs. As previously pointed out, these range from a motivation to retain ownership of valuable materials (e.g., Man3), to reduce supply chain dependency (Con8), or the prospect of making a profit by establishing a recycling business segment (Con9). It remains an open question whether this means that specialization, economies of scale, and division of labor (Smith, 1998) are less relevant in a CE or whether the decisions of CE frontrunners against specialization are simply born out of necessity, as networks and CE infrastructure are currently still lacking. Theory on the competitive advantage of companies (Porter, 1985) would expect coalitions with other firms to form in a CE as well so that companies in the construction and manufacturing industries can, once again, focus on core products and competencies. Whether this will be the case in the future remains to be seen.

# 6. Opportunities for further research

Despite a growing number of contributions in recent years (de Jesus et al., 2021; Suchek et al., 2021), the research field on innovation and the CE can still be categorized as emerging. As an exploratory study in an emerging research field, this dissertation provides multiple contributions to literature, each bringing opportunities for further research. The following sections describe areas that present particularly interesting opportunities for further exploration. However, it is essential to note that there may be other relevant aspects that can be deducted from the presented findings. Therefore, this should be seen as a clear invitation to conduct further exploratory studies on the role of innovation and innovation capabilities in implementing the CE.

*Further exploration of the role of core products and competencies and business model expansion along the value chain*

The need for further research in this area has already been described in the previous paragraphs of section 5.4. The introduction of complex CBMs by the CE frontrunners interviewed in this dissertation extending beyond what these companies traditionally focused on in a linear economy suggests that specialization and a focus on core products and competencies (Prahalad & Hamel, 1990) could be less relevant in a CE. Future research needs examine whether this trend continues as the CE matures, or whether, as Porter (1985) would suggest, coalitions among companies form and producers revert to focusing on core products and competencies.

*Exploring the role of innovation capabilities among various actors in the circular value chain*

The sample of this dissertation's qualitative study comprises producers from the construction and manufacturing industries in Germany. The study deliberately focuses on this specific group of actors to derive concrete recommendations for other producers in these two industries. However, as argued previously, innovation in a CE is increasingly dependent on a set of actors and can rarely succeed without collaboration (Konietzko et al., 2020; Schmitt & Hansen, 2018). Producers need to develop new capabilities they did not need for linear innovations, and they need to adapt other capabilities, as they have a different weight in a CE context (Figure 25, Table 25). Future research should explore which innovation capabilities other actors along the circular value chain in both industries need to contribute to circular innovation successfully.

For example, what new capabilities do suppliers need to develop new circular materials, or how do they need to adapt existing capabilities? The construction industry, in particular, involves additional groups of actors (architects, structural engineers, developers, and carpenters). What innovation capabilities do these actor groups need in a CE that they did not have before?

It is important to address these questions, to advance the discussion on innovation capabilities and the CE. A comprehensive overview of relevant innovation capabilities across all relevant actor groups is necessary to promote large-scale CE implementation.

*The role of innovation newstream and mainstream activities*

A second opportunity for future research concerns the role of *innovation newstream and mainstream activities* in relation to innovation capabilities for CE implementation. These elements are central to the innovation capability model (Figure 10), which was originally proposed by Lawson and Samson (2001) and served as a guiding framework for evaluating the qualitative study's findings in this dissertation. However, due to scope limitations, the role of *innovation newstream and mainstream activities* could not be explored in this dissertation. Lawson and Samson (2001, p. 389) themselves argue that "the innovation capability will influence the configuration of newstream and mainstream activities leading to continuous product, process and systems innovation." This configuration is crucial, as firms need to allocate their limited resources between their mainstream activities and new innovation activities, such as the new development of circular products.

Future research could address this and help to answer two important questions: How do the innovation capabilities required for newstream- and mainstream activities differ for companies that develop new, circular products? How can companies find the right balance between newstream- and mainstream activities in their transition to a Circular Economy? The discussion of CE-specificity of innovation capabilities (Figure 25) can serve as a basis for any future research attempting to answer the first of these two questions.

*Advancing the discussion on decision-making for circular innovations*

Thirdly, there is a need for further studies exploring the decision-making process concerned with the implementation of circular innovations in more detail. While multiple studies have proposed and compared different metrics to measure circularity (Corona et al., 2019), contributions concerned with strategic decision-making on a firm level remain largely absent. This dissertation proposes a framework (Figure 22, Figure 23) to address this gap and guide firms in the decision-making process. It was developed based on insights from the interviews with CE frontrunners and includes aspects from the wider literature on decision-making in the context of sustainability (McKinsey & Company, 2007; Porter & Kramer, 2006, 2011). This dissertation explicitly invites future research to test the framework and expand it, if necessary, for example, through in-depth case studies with CE frontrunners.

*The role of business analytics capabilities*

Lastly, and maybe most obviously, the quantitative study's findings on the importance of business analytics capabilities (BAC) alongside innovation capabilities (ICA) present a further opportunity for future research (Table 20). Similar to how the qualitative study has explored the role of innovation capabilities, there is a significant opportunity for future studies to examine how CE frontrunners have used business analytics to advance CE implementation and which capabilities they have developed in the process. Such research could not only advance the research debate around these two dynamic and growing research fields but also, as this dissertation aspired to do, derive significant, pragmatic recommendations for managers of firms looking to implement the CE. The studies by Kristoffersen et al. (2021a, 2021b) can serve as a starting point for research in this area. Existing literature focuses largely on the potential of business analytics or digital technologies (Bressanelli et al., 2018; Ellen MacArthur Foundation, 2016; Liu et al., 2022). Future studies should expand on this research and focus on capabilities rather than business analytics technologies alone.

# 7. Conclusion

This dissertation has examined how companies can leverage innovation to implement a Circular Economy in the construction and manufacturing industry in Germany. It responds to calls “to understand how, and by which means, innovation is able to facilitate the emergence of a CE” (de Jesus & Mendonça, 2018, p. 76), addressing a literature gap, as existing CE research has placed “little emphasis (…) on mechanisms for implementing innovation in circular contexts and types of innovation relevant to the CE” (Sehnem et al., 2021, p. 241).

A first, quantitative PLS-SEM study conducted among construction and manufacturing companies operating in Germany found that both (perceived) business analytics and (perceived) innovation capabilities positively influence (perceived) CE implementation. Furthermore, it has identified a significant and positive effect of (perceived) CE implementation on (perceived) firm performance. However, no significance has been found for the lower-order construct of financial performance (Figure 18, Table 19 & Table 20).

These findings have crucial managerial and research implications. For individual companies they signal that introducing circular products or business models can enhance their firm performance. Developing innovation capabilities and business analytics capabilities can help companies struggling with CE implementation to overcome implementation barriers. In light of the continuingly low CE implementation rates worldwide (Circle Economy, 2024), this finding is encouraging from an overall CE perspective, as it shows that implementing CE initiatives can be an advantage for individual companies. The insights also confirm that previous research’s findings on the effect of innovation capabilities on CE implementation (Jakhar et al., 2018) and CE implementation on firm performance (Khan et al., 2020; Kristoffersen et al., 2021a) hold true in highly complex and waste-intensive industries, such as construction and manufacturing.

Building upon these insights, and especially on the finding that innovation capabilities positively impact CE implementation, a subsequent qualitative, interview-based study was conducted among CE frontrunners in Germany’s construction and manufacturing industries. This study provided detailed insights into how CE frontrunners leverage innovation for the successful implementation of the CE on a firm level. It also examined how innovation capabilities can help them in this process.

An exploratory research approach revealed implementation-orientated findings at a very detailed level, as demanded by research on multiple occasions (de Jesus et al., 2021; Drabe (née Geng) & Herstatt, 2016). The interviews confirm the vital role of innovation for CE implementation. In this context, the qualitative study provides three essential findings.

Firstly, reinforcing earlier research (Prieto-Sandoval et al., 2018), the study finds that CE frontrunners in the construction and manufacturing industries have chosen different types of innovation, ranging from (production) process innovation to circular business model innovation (Figure 19). Secondly, the interviews provide detailed insights into the decision-making process regarding the introduction of the respective innovations among CE frontrunners. These insights are summarized in a decision-making framework to provide guidance to companies across both industries that are looking to implement circular innovations in the future (Figure 22). Thirdly, and maybe most importantly, the qualitative study reveals specific innovation capabilities that have enabled CE frontrunners to implement various types of circular innovations successfully. Expanding an established framework from innovation literature (Lawson & Samson, 2001), 38 concrete capabilities are identified and described across nine dimensions (Table 25). From a managerial perspective, these detailed insights into innovation capabilities among CE frontrunners should provide firms in the construction and manufacturing industries with concrete guidance how to leverage innovation for implementing the CE.

One of the main findings of this dissertation is that innovation capabilities in the context of circular innovations can be classified into three distinct types (Figure 25). Some capabilities can support circular innovation similarly to linear innovation and, therefore, do not need to be adapted by companies. In contrast, other capabilities encountered among CE frontrunners are less relevant in a linear economy and need to be developed specifically for a Circular Economy. However, most of the capabilities identified in this dissertation fall between these two categories. These capabilities are relevant in the development of both linear products and business models, as well as in a CE context. However, upon closer inspection, they often have small but significant differences. For instance, circular innovations frequently involve an expanded group of actors (Konietzko et al., 2020; Schmitt & Hansen, 2018) or occur against the backdrop of more consumer skepticism towards circular products or business models (Grafström & Aasma, 2021; Vermunt et al., 2019). As circular innovations face changed framework conditions, the requirements for innovation capabilities are also changing.

Understanding that some innovation capabilities must be adapted for circular innovations is vital. Failure to acknowledge this can put even the most innovative companies in a linear economy at risk of failing to implement circular innovations. Conversely, recognizing these small but significant differences, and thus recognizing that existing innovation capabilities often have a different weighting for circular innovation and need to be adapted accordingly, can be the first step for companies in a successful transition to the Circular Economy.

# 8. Reference list

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# 9. Appendix

## 9.1. Appendix A: Online survey used for the quantitative study

Sehr geehrte/r Befragte/r,

das Ziel dieser Umfrage ist es, herauszufinden, welche Business Analytics, digitalen und anderen Faktoren eine erfolgreiche Umsetzung von Praktiken der Kreislaufwirtschaft (Circular Economy) in Unternehmen beeinflussen.

Diese Umfrage wird von der Technischen Universität Hamburg (TUHH) in Kollaboration mit der Universität Tampere, Finnland durchgeführt. Für die Beantwortung der Umfrage benötigen Sie ca. 15-20 Minuten.

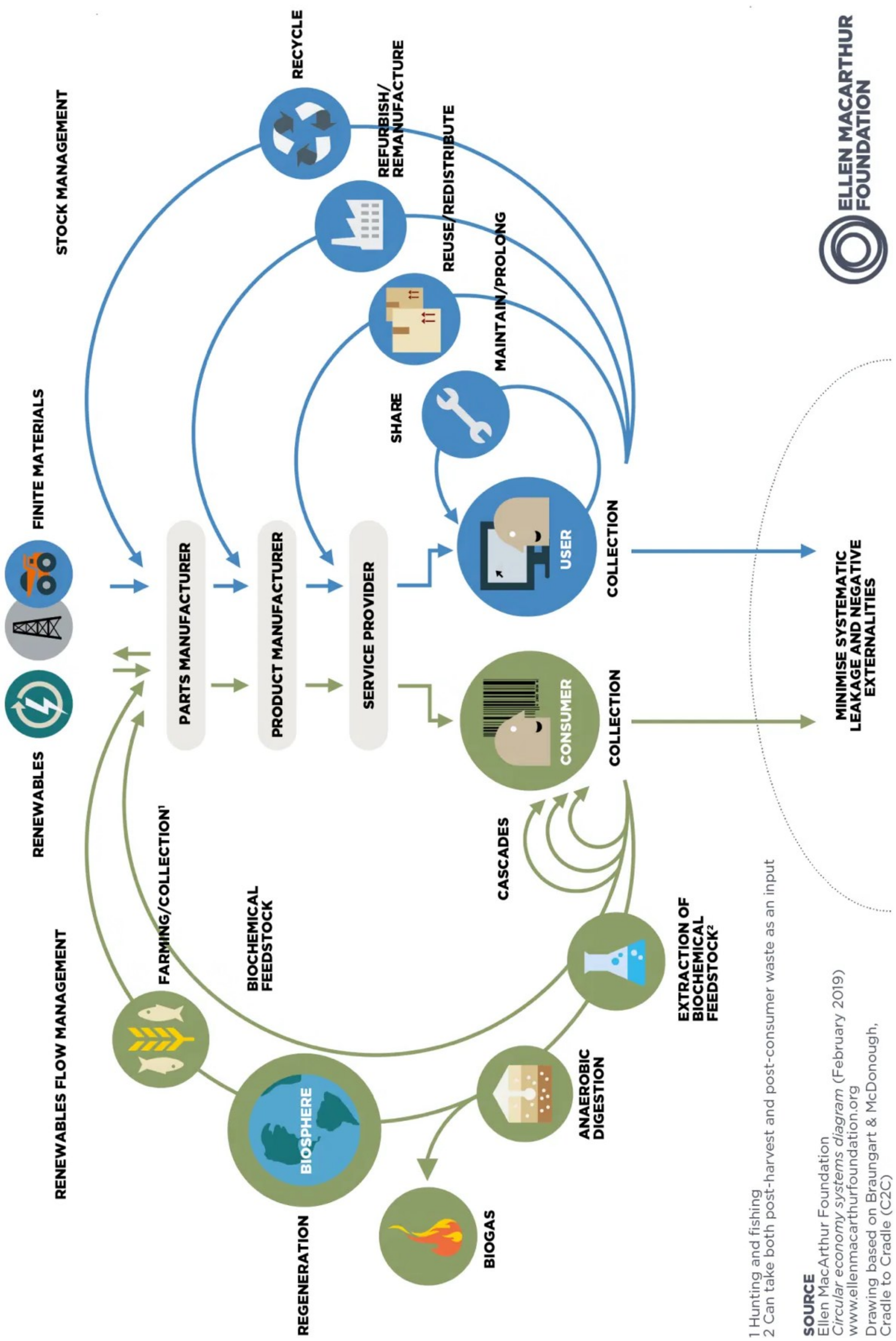
Dies ist eine anonyme Umfrage. In den Umfrageantworten werden keine persönlichen Informationen über Sie gespeichert, es sei denn, in einer Frage wird explizit danach gefragt.

### Dies ist eine anonyme Umfrage.

In den Umfrageantworten werden keine persönlichen Informationen über Sie gespeichert, es sei denn, in einer Frage wird explizit danach gefragt.

Wenn Sie für diese Umfrage einen Zugangscode benutzt haben, so können Sie sicher sein, dass der Zugangsschlüssel nicht zusammen mit den Daten abgespeichert wurde. Er wird in einer getrennten Tabelle aufbewahrt und nur aktualisiert, um zu speichern, ob Sie diese Umfrage abgeschlossen haben oder nicht. Es gibt keinen Weg, die Zugangscodes mit den Umfrageergebnissen zusammenzuführen.

Weiter




Note: In the survey, the diagram above was shown to the participants in German. As the resolution of the German diagram is too low, the English version of the diagram is included in this publication.

## Industriezweig

*1. In welchem Wirtschaftszweig ist Ihr Unternehmen tätig?

Bitte wählen Sie eine der folgenden Antworten:

- ○ Baugewerbe (Bau von Gebäuden aller Art, einschließlich Neubauten, Reparaturen, An- und Umbauten, Errichtung von vorgefertigten Gebäuden oder Konstruktionen, Bau von ganzen Wohnhäusern, Bürogebäuden, Geschäften und anderen öffentlichen Gebäuden und Versorgungseinrichtungen, landwirtschaftlichen Gebäuden usw.)
- ○ Herstellung von Computer-, Elektronik- und optischen Produkten
- ○ Herstellung von elektrischen Anlagen
- ○ Herstellung von Maschinen und Anlagen (weitere)
- ○ Herstellung von Kraftfahrzeugen, Anhängern und Sattelanhängern
- ○ Herstellung von sonstigen Fahrzeugen und Transportmitteln
- ○ In einer anderen Industrie

## Kurze Definition der in der Umfrage verwendeten Begriffe

„Die Kreislaufwirtschaft bezieht sich auf eine industrielle Wirtschaft, die von ihrer Intention her restaurativ ist, auf erneuerbare Energien setzt, den Einsatz giftiger Chemikalien minimiert, verfolgt und eliminiert; und Abfall durch sorgfältiges Design verhindert“ (Ellen MacArthur Foundation, 2013).

„Das Diagramm veranschaulicht den kontinuierlichen Fluss von technischen und biologischen Materialien durch den Wertkreislauf.“ (Ellen MacArthur Foundation, 2019). Auf der linken Seite ist der biologische Kreislauf dargestellt, während auf der rechten Seite der Kreislauf für technische Materialien abgebildet ist.

## Business Analytics Fähigkeiten

*Bitte geben Sie an, inwieweit die folgenden Aussagen die aktuelle Situation in Ihrem Unternehmen widerspiegeln, und zwar auf einer Skala von 1-7 (1. Stimme überhaupt nicht zu, 2. Stimme nicht zu, 3. Stimme eher nicht zu, 4. Stimme weder zu noch nicht zu, 5. Stimme eher zu, 6. Stimme zu, 7. Stimme vollkommen zu).

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | Stimme weder zu noch nicht zu | Stimme eher zu | Stimme zu | Stimme vollkommen zu | Ich weiß es nicht |
|---|---|---|---|---|---|---|---|---|
| 2. Unser Unternehmen verfügt über hohe Business Analytics Fähigkeiten. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 3. Wir haben Zugang zu qualitativ hochwertigen Daten. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 4. Wir verfügen über angemessene finanzielle Mittel, um neue Business Analytics Tools zu testen und einzusetzen und haben Arbeitszeit für Ihre Erprobung eingeteilt. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 5. Wir haben die erforderliche IT-Technologie in unserem Unternehmen implementiert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 6. Unsere Manager besitzen die Fähigkeit zum 'System-Thinking'. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 7. Wir haben Data-Science-Fähigkeiten in unserem Unternehmen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 8. Wir verfolgen eine datengetriebene Kultur. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 9. Unsere Innovationskultur hat Ziele im Bereich der Kreislaufwirtschaft. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 10. Wir fördern Offenheit und 'Co-Creation'. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

# Fähigkeiten zur Ressourcensteuerung und -verwaltung

*Bitte geben Sie an, inwieweit die folgenden Aussagen die aktuelle Situation in Ihrem Unternehmen widerspiegeln, und zwar auf einer Skala von 1-7 (1. Stimme überhaupt nicht zu, 2. Stimme nicht zu, 3. Stimme eher nicht zu, 4. Stimme weder zu noch nicht zu, 5. Stimme eher zu, 6. Stimme zu, 7. Stimme vollkommen zu).

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | Stimme weder zu noch nicht zu | Stimme eher zu | Stimme zu | Stimme vollkommen zu | Ich weiß es nicht |
|---|---|---|---|---|---|---|---|---|
| 11. Wir sind effektiv darin, wertvolle IT-Ressourcen/Assets von Lieferanten zu beschaffen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 12. Wir sind effektiv darin, wertvolle IT-Ressourcen/Assets intern zu entwickeln. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 13. Wir sind effektiv darin, weniger wertvolle IT-Ressourcen/Assets außer Betrieb zu nehmen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 14. Wir sind effektiv darin, IT-Ressourcen/Assets zu integrieren, um IT-Fähigkeiten aufzubauen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 15. Wir sind effektiv darin, bestehende IT-Fähigkeiten mit neuen IT-Ressourcen/Assets zu bereichern, bzw. zu erweitern. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 16. Wir sind effektiv darin, neue IT-Fähigkeiten zu entwickeln, bzw. zu schaffen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 17. Wir sind effektiv darin, unsere IT-Fähigkeiten für eine gemeinsame Vision zu mobilisieren. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 18. Wir sind effektiv darin, unsere IT-Fähigkeiten zu koordinieren, bzw. zu integrieren. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 19. Wir sind effektiv darin, unsere IT-Fähigkeiten einzusetzen, um spezifische Marktchancen zu nutzen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

## Innovationsfähigkeiten

*Bitte geben Sie an, inwieweit die folgenden Aussagen die aktuelle Situation in Ihrem Unternehmen widerspiegeln, und zwar auf einer Skala von 1-7 (1. Stimme überhaupt nicht zu, 2. Stimme nicht zu, 3. Stimme eher nicht zu, 4. Stimme weder zu noch nicht zu, 5. Stimme eher zu, 6. Stimme zu, 7. Stimme vollkommen zu).

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | Stimme weder zu noch nicht zu | Stimme eher zu | Stimme zu | Stimme vollkommen zu | Ich weiß es nicht |
|---|---|---|---|---|---|---|---|---|
| 20. In diesem Unternehmen werden ständig neue Produkt- oder Dienstleistungsideen entwickelt. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 21. Wir suchen ständig nach neuen Wegen, Dinge zu tun. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 22. Unsere Arbeits- und Vorgehensmethoden sind kreativ. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 23. Dieses Unternehmen ist in der Regel ein Pionier auf dem Markt. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 24. Die Forschung und Entwicklung in diesem Unternehmen unterstützten die häufige Einführung neuer Produkte oder Dienstleistungen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 25. Unser Unternehmen versucht, neue Ideen und Innovationen an den Markt zu bringen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

## Umsetzung der Kreislaufwirtschaft

*Bitte geben Sie an, inwieweit die folgenden Aussagen die aktuelle Situation in Ihrem Unternehmen widerspiegeln, und zwar auf einer Skala von 1-7 (1. Stimme überhaupt nicht zu, 2. Stimme nicht zu, 3. Stimme eher nicht zu, 4. Stimme weder zu noch nicht zu, 5. Stimme eher zu, 6. Stimme zu, 7. Stimme vollkommen zu).

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | Stimme weder zu noch nicht zu | Stimme eher zu | Stimme zu | Stimme vollkommen zu | Ich weiß es nicht |
|---|---|---|---|---|---|---|---|---|
| 26. Wir bieten Wertangebote, die von materieller Nutzung entkoppelt sind (z.B. Verzicht auf ein physisches Produkt zugunsten einer digitalen Dienstleistung). | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 27. Wir unterstützen Produkte während ihrer Lebensdauer durch die Bereitstellung von Ersatzteilen und/oder Reparaturdienstleistungen als separate Verkaufsangebote. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 28. Wir bieten das Ergebnis oder die Leistung eines Produkts als Dienstleistung an, anstatt das physische Produkt zu verkaufen (z.B. leistungsbezogene Geschäftsmodelle). | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 29. Wir bieten den Zugang oder die Nutzung des Produktes als Service an, anstatt das physische Produkt zu verkaufen (z.B. nutzungsbasierte Geschäftsmodelle). | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 30. Wir designen für eine einfache Demontage. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 31. Wir beziehen sekundäre, recycelte und/oder erneuerbare Materialien (z.B. Industriesymbiose, Nutzung von Ozeanplastik, nicht-giftiger Materialien oder biologisch abbaubarer Materialien). | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 32. Wir betreiben eine schlanke und saubere und saubere Produktion (z.B. weniger Energie- und Materialverbrauch, Behandlung von Abfall, Nacharbeit). | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 33. Wir optimieren die Produktnutzung und den Betrieb, um die Lebensdauer der Produkte zu verlängern, den Energieverbrauch zu minimieren und/oder die Produktauslastung zu erhöhen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 34. Wir bieten Aktivitäten an, um die bestehenden Nutzungszyklen von Produkten und Teilen zu verlängern (z.B. Upgrade, Reparatur, Wartung). | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 35. Wir bieten Aktivitäten an, um Produkte und Teile auf neue Nutzungszyklen zu erweitern (z.B. Wiederverwendung, Überholung, Wiederaufbereitung). | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 36. Wir bieten Aktivitäten an, um die Lebensspanne von Materialien zu verlängern (z.B. Recycling, Cascading, Energierückgewinnung). | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

## Unternehmensperformance

*Bitte geben Sie an, inwieweit die folgenden Aussagen die Veränderung der Perfomance Ihres Unternehmens in den letzten Jahren widerspiegeln, und zwar auf einer Skala von 1-7 (1. Stimme überhaupt nicht zu, 2. Stimme nicht zu, 3. Stimme eher nicht zu, 4. Stimme weder zu noch nicht zu, 5. Stimme eher zu, 6. Stimme zu, 7. Stimme vollkommen zu).

| | Stimme überhaupt nicht zu | Stimme nicht zu | Stimme eher nicht zu | Stimme weder zu noch nicht zu | Stimme eher zu | Stimme zu | Stimme vollkommen zu | Ich weiß es nicht |
|---|---|---|---|---|---|---|---|---|
| 37. Wir haben den Energieverbrauch reduziert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 38. Wir haben das Abfallaufkommen reduziert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 39. Wir haben die Luftverschmutzung reduziert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 40. Wir haben die Herstellungs-/Betriebskosten reduziert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 41. Wir haben den Jahresumsatz gesteigert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 42. Wir haben den Marktanteil gesteigert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 43. Wir haben unsere Fähigkeiten gesteigert, innovative Produkte/Dienstleistungen einzuführen. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 44. Wir haben die Qualität von Produkten/Dienstleistungen gesteigert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 45. Wir haben den Markenwert von Produkten/Dienstleistungen verbessert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 46. Wir haben die Zugangsmöglichkeiten zu neuen Märkten gesteigert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 47. Wir haben das Unternehmensimage bei den Kunden verbessert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 48. Wir haben die Beziehung mit Lieferanten/lokalen Gemeinschaften/Regulierungsorganisationen verbessert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 49. Wir haben die Zufriedenheit und die Unterstützung von Investoren/Partnern gesteigert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 50. Wir haben die Zufriedenheit und Loyalität der Mitarbeiter/Mitarbeiterinnen gesteigert. | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

## Hintergrundinformationen

*51. Wie viele Beschäftigte hat Ihr Unternehmen ungefähr?

Bitte wählen Sie eine der folgenden Antworten:

- ○ 1–9
- ○ 10–49
- ○ 50–249
- ○ 250-500
- ○ >500

*52. Wie alt ist Ihr Unternehmen ungefähr?

Bitte wählen Sie eine der folgenden Antworten:

- ○ <1 Jahr
- ○ 1–4 Jahre
- ○ 5–9 Jahre
- ○ 10–49 Jahre
- ○ 50+ Jahre

*53. Welche Position habe Sie in dem Unternehmen inne?

Bitte wählen Sie eine der folgenden Antworten:

Bitte auswählen ...

*54. Wie lange arbeiten Sie selbst schon für das Unternehmen?

Bitte wählen Sie eine der folgenden Antworten:

- <1 Jahr
- 2-3 Jahre
- 4-5 Jahre
- 5-10 Jahre
- 10-15 Jahre
- 15-20 Jahre
- >20 Jahre

*55. Seit wie vielen Jahren, falls überhaupt, setzt Ihr Unternehmen IT gestützte Business Analytics ein?

Bitte wählen Sie eine der folgenden Antworten:

- <1 Jahr
- 1–3 Jahre
- 3–5 Jahre
- 5+ Jahre
- Wir setzen IT gestützte Business Analytics nicht ein.

*56. Inwieweit beinhaltet die Strategie Ihres Unternehmens die Kreislaufwirtschaft?

Auch wenn Sie nicht mit den Prinzipien der Kreislaufwirtschaft arbeiten, versuche Sie bitte die Fragen zu beantworten. Ihre Antworten sind sehr wertvoll für uns.

Bitte wählen Sie eine der folgenden Antworten:

- Gar kein Teil der Strategie
- Ein Teil unserer Gesamtstrategie
- Einer der Kernpunkte unserer Strategie

*57. Seit wie vielen Jahren arbeitet Ihr Unternehmen mit der Kreislaufwirtschaft?

Bitte wählen Sie eine der folgenden Antworten:

- <1 Jahr
- 1–3 Jahre
- 3–5 Jahre
- 5+ Jahre
- Wir arbeiten nicht mit der Kreislaufwirtschaft.

*58. In welchem Land ist Ihr Unternehmen registriert?

*59. Wie ist die Eigentumsstruktur Ihres Unternehmens?

Bitte wählen Sie eine der folgenden Antworten:

- Börsennotiert
- in Staatsbesitz
- in Familienbesitz
- in Privatbesitz

*60. Bitte geben Sie Ihr Geschlecht an.

Bitte wählen Sie eine der folgenden Antworten:

- Männlich
- Weiblich
- Divers
- Ich möchte keine Angabe machen

*61. Bitte geben Sie Ihr Alter an.

Bitte wählen Sie eine der folgenden Antworten:

- <18
- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65 und älter

*62. Bitte geben Sie Ihren höchsten Bildungsabschluss an.

Bitte wählen Sie eine der folgenden Antworten:

- ○ Weiterführende Schule
- ○ Gymnasialabschluss
- ○ Berufsausbildung
- ○ Bachelor
- ○ Master
- ○ Promotion (Doktor)
- ○ Ich möchte keine Angabe machen

*63. In welchem Bundesland wohnen Sie?

Bitte wählen Sie eine der folgenden Antworten:

Bitte auswählen ...

# Optionales Feedback

Sie können an dieser Stelle weiteres Feedback zur Umfrage selbst hinterlassen, etwa zu Themen, die wir Ihrer Meinung nach nicht abgedeckt haben, die wir aber in unserer Forschung berücksichtigen sollten:

Wenn Sie über die Ergebnisse der Studie auf dem Laufenden gehalten werden möchten oder Interesse an der Teilnahme an weiterführenden Interviews haben, hinterlassen Sie bitte nachfolgend Ihre E-Mail-Adresse:

Vielen Dank für Ihre Teilnahme!

Wir wissen es sehr zu schätzen, dass Sie sich die Zeit genommen haben, diese Umfrage zu beantworten. Ihr Beitrag ist außerordentlich wertvoll und wichtig für unsere Forschung.

Falls Sie Fragen zu der Umfrage haben, zögern Sie bitte nicht, sich an folgende Adressen zu wenden: matthias.schneider@tuhh.de oder ulla.saari@tuni.fi.

Herzliche Grüße,

Dr. Ulla Saari, Matthias Schneider (Doktorand)

## 9.2. Appendix B: Interview questionnaire of the qualitative study

1. Let us begin by talking a bit about you. Could you shortly describe your role in your company?
    a. *For how long have you been working with your company?*
    b. *For how long have you been working in your current position and what are your tasks and responsibilities?*
    c. *Which touchpoints do you have at your work with innovation and the development of new products?*
    d. *Which touchpoints do you have with circular products and initiatives in the area of the circular economy?*
2. With regard to circular products or those that can at least partially be considered circular – could you describe one or multiple circular products of your company? In what way do these products include circular aspects?
3. To what extent have there been innovations to make this product circular?
    a. In the area of product innovation?
    b. In the area of business model innovation?
4. Do these considerations take place for both existing as well as new products? Is there a distinction?
5. At what point in the innovation process do considerations about circularity take place?
    a. *Idea- and Concepts Development*
    b. *Development and Testing*
    c. *Production and Market Launch*
    d. Which stakeholders have been involved in the process?
    e. Is there a part of this process that was particularly crucial for you in the development of circular products?
6. If you compare this process with the „standard process" for similar, linear products – which differences are there?

    a. In case there are any differences, what is the reason you have made these changes?

7. Which effects have these changes in the innovation process, or the introduction of circular products had on the work of your company?
    a. What had to be changed in the workflows and processes?
    b. Were there any complications?
    c. Which departments were particularly affected?
    d. Which stakeholders (suppliers, customers, etc.) were especially affected?
8. How did you deal with these challenges as a company?
9. What have you done to support the innovation process for circular products?
    a. *How did the overall company strategy influence the innovation process for circular products? Have you maybe even made changes to the strategy?*
    b. *Did you have to change anything in terms of technology?*
    c. *Have there been changes to the organizational structure?*
    d. *Did you have enough resources (knowledge, financial, technology) to launch the product?*
        i. *How have you ensured that existing resources were used successfully?*
    e. *How have you dealt with partners and how have you involved them?*
    f. *Have you educated or trained your employees?*
        i. *Did you motivate or did you have to motivate employees? If yes, how have you done that?*
    g. *What influence did your corporate culture have on the success of the innovation process?*
        i. *Have there been changes to the corporate culture? Were they actively promoted?*
    h. *Did the management or the leadership style in your company have an influence on the innovation process for the circular products?*
    i. *Which role did digitalization and business analytics play in the process?*

i. *Do you see additional areas, in which you can or want to use business analytics solutions for the development and introduction of circular products?*

10. In hindsight, which of these measures would you say has had a positive effect on the innovation process?
11. What would you do differently for the next product to make the innovation process more successful?
    a. Are there currently any weaknesses that you are observing?
    b. Where are opportunities for improvement in your opinion?
    c. Do you know why they have not been implemented yet?
    d. Are there any interesting developments that you observe at your competitors in that regard?
12. In your opinion, is there anything else that I should know with regards to my research on this topic and that you would like to share with me?