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As attention around environmental sustainability themes is increasing, a multiple attribute environmental sustainability philosophy called Cradle to Cradle (C2C) has recently been developed and presented. The C2C concept provides a new vision of environmental sustainability to companies, to do “more good” to the environment rather than “less bad”. An important and central aspect is to eliminate the concept of waste by closing technical as well as biological cycles.

The aim of this paper is to analyze which factors from closed-loop supply chain management can facilitate the realization of the technical cycle of C2C certified products. Based on six case studies of different companies, we investigate which factors of existing closed-loop supply chain concepts are critical for the C2C technical cycle. Altogether this research links the theory of closed-loop supply chains to the concept of C2C and provides new insights concerning successful implementation of the technical cycle.

Keywords: Cradle to Cradle, Product Recovery, Closed-loop Supply Chain, Sustainability

1 Introduction

Sustainability and environmental themes are receiving much attention in all kinds of communities and forums around the world (Bjørn and Hauschild, 2013). In order to deal with increasing waste and pollutions as well as scarcity of natural resources the concept of a circular economy gains popularity (Ellen MacArthur Foundation, 2012, 2013, 2014). Based on the general theory of circular economy, the US-American architect William McDonough and the German chemist Michael Braungart introduced a multiple attribute environmental sustainability philosophy called "Cradle to Cradle" (C2C) through their book "Cradle to Cradle - Remaking the way we make things" (2002).

C2C is a relatively new sustainability approach that is opposite to the familiar and traditionally followed cradle to grave paradigm in which resources are extracted, used and disposed of (Bolus et al., 2013, McDonough and Braungart, 2002). Cradle to cradle reflects an idea in which the materials are treated as resources and flow perpetually in a cyclical metabolism without losing their quality (Braungart et al., 2007). In order to realize this circular industrial system, it is necessary that the material flows are redirected and do not end at waste disposal sites (Braungart et al., 2007). This redirection of material flows can be enabled by closed-loop supply chains and reverse logistics.

The aim of this paper is to analyze which factors from closed-loop supply chain management can facilitate the realization of the technical cycle of C2C certified products. Supply chains of six existing C2C products from different companies are investigated. Based on a framework for product recovery, factors of existing closed-loop supply chain concepts are analyzed

concerning their impact on the C2C technical cycle. Altogether, the theory of closed-loop supply chains is integrated into the concept of C2C in order to provide new insights concerning successful implementation. Furthermore, our analysis of C2C supply chains also enriches closed-loop supply chain theory.

In the next section, theories and concepts relevant to this research are presented. This includes the C2C process, closed-loop supply chains and reverse logistics as well as a framework for product recovery in closed-loop supply chains. Section three describes the qualitative research approach chosen. Afterwards, findings of the case studies are presented. The paper concludes with a discussion of results and an outlook on future research.

2 Theoretical Foundations

This section outlines the theoretical background needed to answer the research question. First, the Cradle to Cradle process is explained. Second, the concepts of closed-loop supply chain and reverse logistics are defined. Third, the theoretical foundations are closed with a description of a traditional closed-loop supply chain framework.

2.1 Cradle to Cradle Process

Published in 2002, the book "Cradle to Cradle - Remaking the way we make things" by McDonough and Braungart has introduced a new paradigm of producing and consuming to both academics and practitioners. Today, the concept is widely discussed in different industries and institutes world-

wide (Bjørn and Hauschild, 2013). Furthermore, many companies have implemented C2C standards and achieved a certification for their efforts. Currently, there are more than 150 companies worldwide holding a C2C certificate for over 370 products (Cradle to Cradle Products Innovation Institute, 2015).

The C2C paradigm formulates a new perspective for the development of products and services and is understood as the conceptual counterpart to the cradle-to-grave concept, which in turn frames the take-make-waste economy (Bjørn and Hauschild, 2013, Bolus et al., 2013). "Cradle-to-cradle design enables the creation of wholly beneficial industrial systems driven by the synergistic pursuit of positive economic, environmental and social goals." (Braungart et al. 2007, p. 1343). In line with the shift to a circular economy system, Braungart and McDonough suggest to focus on eco-effectiveness instead of eco-efficiency, which is the more common concept representing the target of reduced emissions and decrease of negative externalities (Huesemann, 2004). Ultimately, through eco-effectiveness C2C aims for a "transformation of products and their associated material flows such that they form a supportive relationship with ecological systems and future economic growth" (Braungart et al. 2007, p. 1338). This shift from efficiency to effectiveness leads to a redefinition of waste (Bjørn and Hauschild, 2013, McDonough and Braungart, 2013). Hence, it can be said that companies following the C2C process adopt a holistic approach towards environment and society in order to do 'more good' rather than 'less bad'.

The three key pillars of the C2C paradigm are: (1) Waste equals food, (2) Use current solar income and (3) Celebrate diversity (McDonough et al., 2003).

These principles are complemented by the idea of two cycles (called metabolisms) which integrate either biological or technical nutrients in a cyclical flow (see figure 1). The focus of this research effort is on the technical metabolism which addresses products that are not compostable or natural but can be ideally disassembled after their use phase. The materials that are circulating within this cycle are regarded as technical nutrients and are intended to remain in the cyclical system endlessly without any loss of quality (Braungart et al., 2007, El-Haggar, 2007). Some of the most prominent examples of products processed in such technical cycles are office chairs designed and produced by Herman Miller or Steelcase (Braungart and McDonough, 2011, Rossi et al., 2006).

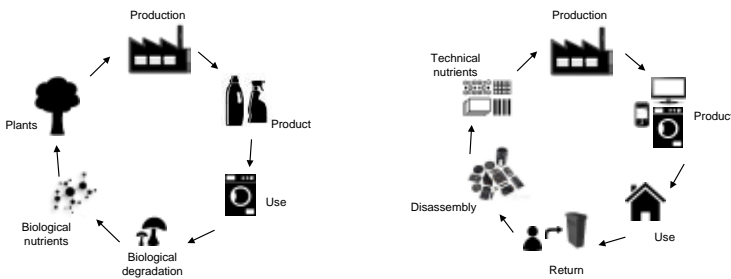


Figure 1 The biological and technical cycle (adapted from EPEA, 2010)

2.2 Closed-Loop Supply Chain and Reverse Logistics

At the beginning of this millennium attention on closed-loop supply chain research was increasing (Savaskan et al., 2004). The growing interest in this topic is also illustrated by the literature review of Govindan et al. (2015) which is based on 382 papers published between 2007 and 2013.

A business definition of closed-loop supply chain management is provided by Guide and van Wassenhove (2009, p.10): "Today we define closed-loop supply chain management as the design, control, and operation of a system to maximize value creation over the entire life-cycle of a product with dynamic recovery of value from different times and volumes of return over time." A closed-loop supply chain can be divided into forward supply chain activities and additional reverse supply chain activities (Govindan et al., 2015, Guide et al., 2003).

Closed-loop supply chain management deals in general with three types of returns (Guide and Van Wassenhove, 2009): (1.) Commercial returns are sent from consumers to the reseller within a limited period after purchase. (2.) End-of-use returns are usually due to technical upgrades entering the market. (3.) End-of-life returns occur when the product can no longer be used or is obsolete. In order to deal with these different types of product returns several activities need to be managed. Reverse logistics covers the acquisition of the product from the consumer, disposition activities as sorting, testing and grading, remanufacturing/ repair as well as remarketing of the recovered product (Guide and Van Wassenhove, 2002, 2009). Similarly, Fleischmann et al. (2000) describe collection, inspection/ separation, re-

processing, disposal and re-distribution as essential steps in a product recovery network. Transportation and storage is needed to link these steps to a reverse supply chain.

Closed-loop supply chains and reverse logistics are an important part of the C2C approach. Since it works on the principle of "Waste equals Food", returned products serve as input either to the technical or the biological metabolism. In consequence, reverse logistics play a pivotal role in moving the end-of-life or end-of-use products (waste) from their point of consumption to points of refurbishment and redistribution as an input material (food) in the technical recovery cycle. It can be expected that the concepts and solutions discussed as closed-loop supply chains and reverse logistics help to understand and manage the technical C2C metabolism. In order to adapt closed-loop supply chain characteristics to a company-specific environment, a framework is suggested in the following section.

2.3 Framework for Product Recovery in Closed-Loop Supply Chains

In their work "A Framework for Reverse Logistics" de Brito and Dekker (2004) elaborate a detailed content analysis of reverse logistics issues. They use a definition of reverse logistics originating from the European Working Group on Reverse Logistics (REVLOG): "The process of planning implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal." (De Brito and Dekker 2004, p.5) Although they focus on the value adding streams of reverse logistics, they emphasize the fact that reverse logistics can contribute to

sustainable development, but should not be seen as an equivalent to green logistics (de Brito and Dekker, 2004). Hence, their framework seems to be the ideal basis for merging C2C and reverse logistics concepts as is the aim of this paper. Furthermore, its holistic perspective addressing the questions "why, what, how, who" constitutes a fertile basis for qualitative case studies. They themselves also used their framework for case study analysis in a subsequent publication (de Brito et al., 2005). Based on the general questions raised in their framework, the following attributes are relevant for our research and investigated in detail:

1. Why are products returned?
 - Drivers
 - Reasons for returns
2. What is returned?
 - Product Characteristics
3. How does reverse logistics work in practice?
 - Collection strategies
 - Recovery methods
4. Who is acting in reverse logistics?
 - Actors

2.3.1 Drivers

Normally it can be said that companies involve in product recovery because of direct and indirect economic gains, legislative reasons or to improve their corporate citizenship (de Brito and Dekker, 2004).

Direct economic gains occur, for example, if companies take advantage of usable parts of returned products in the process of production. Thereby,

they decrease incurred costs for new raw material supplies. Indirect economic gains can result from an improved image of the company. As consumers are increasingly aware of environmental concerns, they appreciate companies that act environment friendly. Hence, companies are able to decrease costs and improve the image of the company (Akdoğan and Coşkun, 2012, Carter and Ellram, 1998, de Brito and Dekker, 2004).

In some cases companies are involved in product recovery due to legislation which mandates them to recover its products or take them back after use (de Brito and Dekker, 2004). Prominent examples are the End-of-life Vehicles Directive (ELV) or Waste Electrical and Electronic Equipment Directive (WEEE) launched by the European Commission. Corporate citizenship programs are used by companies to express that they care for the society including environmental issues, diversity, safety and human rights (Carter and Jennings, 2002). These programs in turn are expected to increase indirect economic gains of the company by an improved reputation.

2.3.2 Reasons for Return

De Brito and Dekker (2004) distinguish between returns that occur due to the distribution network (e.g. recall or commercial returns), manufacturing returns (e.g. faulty products and left overs) and customer returns due to services, guarantees or end-of-life of the products. For our analysis of C2C closed-loop supply chains, it is sufficient to apply the rather broad classification of 'end-of-use' and 'end-of-life' returns.

Returned products which are no longer used by the original owner, but for which a new customer can be found, are categorized as end-of-use returns.

These products might need some repair or remanufacturing, but can be re-introduced to the market. When a product is returned, because it has no remaining use and no new customer can be found, in contrast to the above definition, it has reached the end of its life. Value assessment of end-of-life products is only based on their materials (Guide and Van Wassenhove, 2009, Krikke et al., 2013).

2.3.3 Product Characteristics

Due to the focus on what happens with products after their use phase or their end-of-life, characteristics of the product are of special relevance, i.e. the product's material composition, its recovery potential and the use patterns of consumers during the product life. The product's composition covers aspects that are relevant for the transport of the product and its disassembly, such as product size and the number of components as well as the manner how the components and materials are compound (de Brito and Dekker, 2004).

The factors determining the recovery potential of a product, its deterioration characteristics, are as well a critical attribute. There are three kinds of potential deterioration, intrinsic, economic and homogenous. The first one addresses whether the product ages during the use phase. The economic perspective regards the monetary value and how fast it decreases. The homogeneity covers the question whether the components of the product are subject to equal aging or value decrease processes (de Brito and Dekker, 2004).

How and where the product is used also substantially influences the possibilities of reverse logistics. The use patterns may vary with regards to the

location, duration and intensiveness. Furthermore, the user might be an individual customer or a large corporate business (de Brito and Dekker, 2004).

All these factors have to be considered when developing a product recovery system. In particular, for the recovery of Cradle to Cradle products, the material composition, for example, is important and should ideally be addressed during the product development phase as in this stage toxic materials could be replaced by non-hazardous materials and the components could be composed in a way that facilitates easy disassembly (Braungart et al., 2007, Rossi et al., 2006).

2.3.4 Collection Strategies

Collection strategy refers to the process in which the used products are collected from the consumers and brought to a place for further processing. Collection encompasses auxiliary activities like transporting and storing for further processing. Aras et al. (2010) distinguish two main collection strategies: Drop-off strategy and pick-up strategy. In a drop-off strategy the customer is more actively involved in returning the product to some kind of collection point for used products. Otherwise, a pick-up strategy involves additional actors (producer/ retailer/ third party) in the collection process. Furthermore, three different basic collection models can be characterized based on the actors involved. (1) In the model-M the manufacturer directly collects from the consumer without the involvement of other parties. (2) In the model-R the retailer is active at the interface between manufacturer and consumer. The retailer collects the used products from the consumer and afterwards sells them to the manufacturer. (3) In the model-3P, finally,

another third-party is in charge of the collection process (Kumar and Putnam, 2008, Savaskan et al., 2004).

2.3.5 Recovery Methods

Recovery is the last step after collection and inspection/ selection/ sorting processes of the returned products are completed (de Brito and Dekker, 2004, Fleischmann et al., 2000). Different recovery methods can be distinguished. Direct recovery can occur if the quality of the returned product is good enough for reuse, resale or redistribution without further processing. Otherwise, several options of recovery processes are available including repair, reconditioning, remanufacturing and recycling. Finally, if a returned product cannot be reprocessed due to economic or technical reasons, it needs to be disposed (incineration or land-fill) (de Brito and Dekker, 2004, Fleischmann et al., 2000, King et al., 2006).

A good characterization of these four recovery methods is provided by King et al. (2006). From the different options of recovery, the narrowest loop is a simple repair in which specified faults of the product are corrected. Reconditioning requires more work than repair. Major components of the product are rebuilt, but altogether the quality of the reconditioned product is expected to be less than the quality of a newly manufactured product. In contrast, remanufactured products are supposed to reach the quality of the originally manufactured product with the same warranties. For example, in the 1990s Xerox established remanufacturing facilities for their photocopiers in several countries (King et al., 2006).

Recycling is the process in which the product is recovered at material level. Out of the recovered material new products and components are manufactured. Products to be recycled are dismantled and sorted and processed to recover raw materials (Thierry et al., 1995). Although this is the most widespread recovery method, more energy is needed for recycling compared to the other three recovery methods (King et al., 2006). The choice of an adequate recovery method depends on the quality of the returned product, but also on general product characteristics. An overview of different practices of recovery methods for diverse industries is given in Flapper et al. (2005) or Ferguson and Souza (2010).

Since C2C works on the principle "Waste equals Food", recovery methods are essential to transform the supposed wastes into raw materials for other processes. In this context a distinction between upcycling and downcycling is made. If the recycled material is recovered back into material of at least the same level of quality, then this process is called upcycling. Otherwise, if the product is recycled in such a way that the material recovered is of inferior quality and consequently production of the same high quality product is not possible, this process is called downcycling. In short, upcycling enables materials to retain their status as resources and downcycling just delays dumping of the material at landfills or incineration. In order to create cyclical Cradle to Cradle metabolisms it is necessary to upcycle the products rather than to downcycle (Braungart et al., 2007, McDonough and Braungart, 2002).

2.3.6 Actors

Diverse actors can be involved in reverse logistics of closed-loop supply chains. Depending on the specific processes chosen for collection, recovery and redistribution different actors appear (de Brito and Dekker 2004). For example, looking back at the collection strategies, manufacturers, retailers and/or third parties can be involved. Furthermore, also the customer is an important actor in reverse logistics. He either needs to return the used product or to initiate other collection processes when the useful life of the product ends for him.

Finally, also governmental institutions can play an important role in reverse supply chain management. As described above, legislation can drive companies to initiate reverse supply chains and can also influence the choice of product recovery strategies.

3 Research Approach

Based on the theoretical foundations built in the previous chapter, our research aims to identify factors influencing the reverse supply chain of C2C products. Since this is an explorative form of research, a qualitative research method is chosen. Qualitative research can be done in several ways which include ethnography, grounded theory, narrative analysis, case study analysis etc. (Guest et al., 2013). According to Yin (2003), case study analysis is an appropriate method, if the investigator cannot exert control over the phenomenon and if the focus of the research question is contemporary. Hence, we chose this approach to study C2C closed-loop supply chains.

The method of sampling involved in this research is purposeful sampling. According to Patton (1990, p.169) "the logic and power of purposeful sampling lies in selecting information-rich cases for study in depth". Information-rich cases are the ones from which the researcher can learn a lot regarding the central research question. Altogether six cases were selected based on two criteria as follows:

1. The company should have C2C certified products in its portfolio
2. The company should be involved in the take back and recovery of the same.

Data collection was preliminarily done from resources and documentations available online, for example company websites, annual reports, sustainability reports etc. Furthermore, four telephone interviews were conducted to receive more detailed information.

The following table gives an overview of the six cases studied.

Table 1 Overview of the six case studies

Company, Country	Product	Closed-Loop Supply Chain
Van Gansewinkel Groep, Netherlands	Office paper	Confidential documents are collected and shredded upon the request of the customer. Out of this recycled material new office paper is produced by Steinbeis.

Company, Country	Product	Closed-Loop Supply Chain
Shaw Industries, USA	Carpet	Old carpets are collected and sent for recycling. The recycled material has the same quality as virgin material. Fibers can be reused as fibers and backings can be reused as backings.
Desso, Netherlands	Carpet	Desso collects used carpets and recycles them to a quality equivalent to that of virgin material using a proprietary technology called Re-finity. Fibers are recycled into fibers and backings into backings
Herman Miller, USA	Office furniture	The responsibility of reverse logistics rests with Herman Miller. Old chairs are collected by Herman Miller without any charge to the customer. If possible, chairs are refurbished and reused. Otherwise, the product is disassembled to the elementary level and then transferred to recyclers to recycle them.

Company, Country	Product	Closed-Loop Supply Chain
Ahrend, Netherlands	Office furniture	After use the furniture is collected by Ahrend. Then it is decided if it can be refurbished. If the collected furniture cannot be refurbished it is recycled by Van Gansewinkel.
Royal Auping, Netherlands	Mat- tresses	When delivering new mattresses, Auping offers its customers to collect their old mattresses. The used mattresses are further recycled by Retour Matras.

4 Findings

4.1 Drivers

Anticipated economic benefits were the major motivating factor, both directly and indirectly, to start C2C innovations in products and processes. In all cases studied, responsible managers were convinced of the positive impact C2C implementation will have for the company as well as for the society as a whole.

Direct economic gains include cost savings from using recycled instead of new materials and cost savings from waste reduction. Indirect economic

gains are, however, also very important. For example, the new environmental attributes of the Mirra chair produced by Herman Miller enhanced its market reception (Rossi et al., 2006). Similarly, Desso's EBIT and percentage of sales increased significantly after implementation of the C2C concept (Crainer, 2012). Hence, indirect economic benefits can result from improved products with a positive impact on consumer's health as well as the environment.

Furthermore, all companies described in the case studies have a time-bound corporate social responsibility (CSR) goal concerning take back programs and closing the production loop. These elements of CSR also improve the image of the company and can lead to economic gains. Since CSR goals are top management decisions, the change towards closing the production loop has to come from within the top management.

Legislation and economic benefits interact. If economic benefits of product recycling are higher than traditional disposal strategies, as it is for example the case with paper recycling, then the need for regulations is usually lower.

Hence, not all analyzed C2C cases are situated in an industry influenced by legislation concerning take-back or disposal of end-of-life products. Only the carpet manufacturers (Shaw Industries and Desso) as well as the mattress manufacturer (Auping) act in domains where legislative disposal restrictions exist. However, their C2C efforts surpass legal requirements. Shaw Industries and Desso are actively involved in the upcycling of carpet returns and Auping plans a future upcycling project of mattress returns. Altogether, legislation can positively influence closed-loop supply chains, if end-of-life products harm the environment irreversibly and their disposal

by traditional means (landfills or incineration) is economically more beneficial than recovery processes.

One concrete example on the empowering role of government are the Netherlands. There, Cradle to Cradle is a widely known topic, which is also evident by the numerous examples of C2C products coming from the Netherlands. The Dutch government introduced the National Environmental Policy Plan (NEPP) already in 1989. This plan calls for shared responsibility due to new ambitions and lack of confidence in traditional approaches (Bressers and de Bruijn, 2005). Furthermore, the Dutch government is working with various stakeholders from knowledge institutes, business sectors and social organizations to implement a Policy Document on raw materials which would present a holistic Dutch strategy for raw materials. One of the agenda points of the policy is the closing of cycles by promoting reuse and recycling (Van Gansewinkel, 2011).

4.2 Reasons for Returns

End-of-use returns appear in the two case studies dealing with office furniture supply chains (Hermann Miller and Ahrend). In these cases the C2C products can be disassembled into sub-assemblies. Fleischmann et al. (2000) classify this kind of supply chain as an assembly product remanufacturing network in which the products can be disassembled into individual components. Therefore, it can be concluded that for companies dealing with products which can be disassembled into components repair, reconditioning and remanufacturing are valuable options. In the other cases, only recycling can be used to close the production loop. In these cases end-of-use returns can be compared to end-of-life returns. Hence, the carpet,

mattress and paper manufacturers only focus on recycling the product either themselves or with the help of partners in their reverse supply chain.

4.3 Product Characteristics

The influence of product characteristics on product recovery put forward in the theories of supply chain management is relevant for C2C reverse supply chains, too. Based on our case study analysis the ease of disassembly as well as homogeneity and recyclability of materials seem to be important factors that need to be addressed in the design phase of the product. The cases of carpet supply chains show that ease of disassembly, homogeneity and recyclability of materials are important characteristics to recover old carpets. In the paper supply chain homogeneity of the collected old paper also impacts the quality of the newly recycled paper. Therefore it can be concluded that in order to use product returns as raw material in the same supply chain, recyclability of used materials is a very important aspect. Furthermore, homogeneity of materials and ease of disassembly positively influence product recovery within the same supply chain. The example of Herman Miller points out how important the ease of disassembly can be for the product recovery process. In the course of C2C implementation, they assessed the potential to disassemble the returned product according to different aspects. One aspect was the possibility to disassemble the product using simple tools, such as screwdrivers, in less than 30 seconds (Rossi et al., 2006).

4.4 Collection Strategies

The pickup collection strategy is used in all cases discussed. Based on our findings, it seems to be the most suitable collection strategy for Cradle to Cradle closed-loop supply chains. The collection of used C2C products from the consumers is influenced by three factors: (1.) financial incentives, (2.) level of information and awareness and (3.) level of convenience. Financial incentives are given only indirectly by collecting the product from the consumer without any cost and thereby reducing disposal costs for the consumer. None of the companies pays the consumer for the returned products. Information about the take back program and recovery methods are communicated to the consumer. Only if the consumer is aware about recovery processes and positive effects for him and the environment, he is able to participate. Besides, the take back programs are made as convenient to the consumer as possible by reducing efforts of customers due to collection of the used products. For example, customers of Desso just need to stack the old carpet tiles in a pile which is perceived as a minimal effort from the interviewee. In the case of Van Gansewinkel office paper, the discarders of old paper just need to drop their used paper in an exclusive container specifically provided by Van Gansewinkel for the collection of confidential information. And in the case of Auping, in order to enhance the convenience of the customers, old mattresses are collected when new ones are delivered.

4.5 Recovery Methods

The cases discussed clearly show that products are recovered following traditional reverse logistics steps including collection, inspection, sorting and recovery. As long as materials can be recycled, disposal activities are not found in any of the cases.

Looking at the choice of recovery methods introduced in section 2.3.5, only two of the analyzed cases are involved in recovery methods other than recycling. The manufacturers of office chairs Hermann Miller and Ahrend also repair and recondition the returned chairs if possible. For example, often upholstery of the chair is sufficient in order to resell it. In contrast to the other C2C products analyzed, the office chairs are the only products that can be disassembled. Hence, this exemplifies how product characteristics influence the recovery process.

As already explained, C2C theory distinguishes between upcycling and downcycling of materials. Only upcycling enables endless technical cycles of material reuse. In downcycling processes, although materials are recovered they are not of the same quality as new materials and their final disposal is only delayed. Looking at the cases, it becomes obvious that companies still struggle to realize true upcycling processes. However, Shaw Industries, Desso and Van Ganswinkel use recycled materials actually within the same production cycle. Desso and Shaw Industries have developed their own proprietary technology for separating the fiber from the carpet backing in order to upcycle these materials for their own production process. The paper manufacturer Steinbeis, partnering with Van Ganswinkel in the office paper case, developed an environmental friendly de-inking process to upcycle the collected waste paper (Océ, 2011). Hence, upcycling

often only becomes feasible with the advent of new technologies. As not every component of a returned product can be recycled, sorting and separating process are crucial and influence technologies needed for product recovery.

Auping on the contrary designs its C2C mattresses to ensure recyclability, but so far does not use recycled materials for their new mattresses. Similarly, Hermann Miller and Ahrend give away the sorted materials of their disassembled chairs to external recycling companies, if the chairs cannot be refurbished. Hence, these materials do not stay within the same supply-chain cycle, but recyclability in general is aimed for.

4.6 Actors

Three scenarios can be found in the analyzed cases of C2C closed-loop supply chains:

1. Manufacturers involved in recovery themselves
2. Manufacturers partnering with recyclers in the recovery process
3. Only third-party recyclers involved in recovery

Only Shaw Industries, the world's largest post-consumer carpet recycler, closes the material loop itself without the need of external recycling companies. The office furniture manufacturers Hermann Miller and Ahrend as well as the carpet manufacturer Desso involve external recycling companies into their reverse supply chains. For instance, Aquafil manufactures yarn for Desso from the semi-processed collected used carpets. In the cases of office furniture (Ahrend and Hermann Miller), the manufacturer itself is involved in the refurbishment process when the product is returned due to

end-of-use reasons. But after internal testing and sorting of returned products, parts that cannot be refurbished are passed on to external recycling companies. And the Van Gansewinkel group, a large recycling company from the Netherlands, chose Steinbeis as a manufacturing partner to produce C2C paper. Hence, in four out of six cases collaborations between manufacturers and recyclers enabled closed-loop supply chains. Auping on the contrary is neither involved in collecting, sorting nor recycling of returned mattresses.

It is also important to note that all analyzed case companies cooperate with EPEA (Environmental Protection Encouragement Agency) or MBDC (McDonough Braungart Design Chemistry), the US-American equivalent to EPEA in Europe. These firms support the companies that are striving for C2C implementation and certification with necessary know how on materials and processes. In all cases, these partners were necessary to design the products and develop their supply chains. Moreover, the collaboration with suppliers is facilitated by these partners as EPEA and MBDC can sign non-disclosure agreements with the companies' suppliers and thus get access to data on materials and compositions which the suppliers would usually not like to reveal to the manufacturers due to confidentiality concerns.

One other important actor is the customer of the product who, in all cases, is needed to make the closed-loop supply chain work. In all case studies it was observed that the customer needs incentives, either in the form of financial benefits or high convenience, in order to participate in the return process of the purchased products. These benefits can also result from an additional service offered, as for example the paper shredding in the Van Gansewinkel case. Moreover, the customer influences recycling operations.

If for example in the case of Auping, the customer does not return a dry mattress, the material loses its value and cannot be recycled properly. Furthermore, the customer can facilitate the recovery process through his decision to either buy or lease the product. A leasing option is for example offered by Desso. Therefore, informing the customer about the return process and his role in it is critical for companies which want to establish a C2C closed-loop supply chain.

4.7 Summary of Findings

Based on the above discussions factors influencing the closed-loop supply chain of C2C products processed in technical cycles are identified. An illustration of the coherences is provided in figure 2. It complements the original technical C2C metabolism (see figure 1) presented in section 2.1 with strategic factors relevant at different points of the cycle.

As depicted, economic gains, legislation, and corporate social responsibility influence the actors' involvement in the technical cycle of C2C products. Product characteristics are crucial to enable closed-loop supply chains. Especially material composition and recovery potential of the whole product are issues that need to be addressed in the early phases of the product development and hence influence the production.

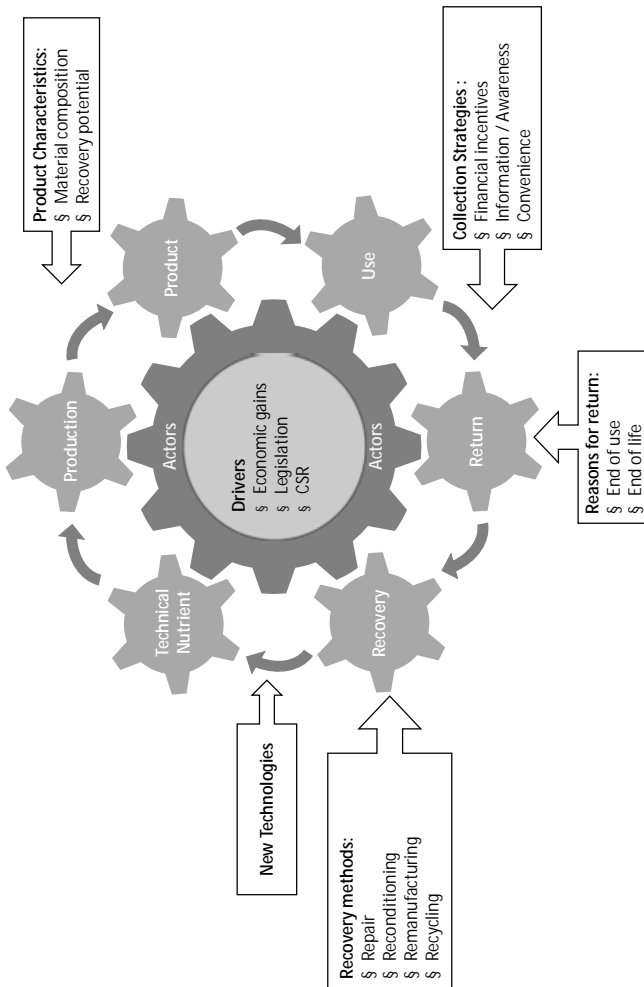


Figure 2 Factors influencing the supply chain of C2C products in the technical cycle (own illustration)

In order to retrieve the used product from the consumer, product collection strategies need to be available. So far, indirect financial incentives and convenience factors for consumers are provided in order to assure the return of used products. Furthermore, the consumer needs to be aware of collection and recovery processes. Insufficient information at this point will result in loss of materials. Products are either returned due to end-of-life or end-of-use reasons. For products that can be disassembled and are returned after the end of their use phase the most valuable recovery methods are repair, reconditioning and remanufacturing. In all other cases, product recovery is implemented as a recycling process in which the product is converted into technical nutrients. Here, in order to reach upcycling instead of downcycling new technologies play a significant role in closing the loop. The objective is to obtain technical nutrients that can eventually be re-used in the production of new products in the same or different supply chain without a significant loss of quality.

5 Conclusion

Theories of closed-loop supply chain management and reverse logistics can be used to expand the C2C product recovery concept. In the presented work, critical factors of closed-loop supply chains have been identified for C2C products on the basis of a product recovery framework. Based on six case studies, the identified factors can guide managers in implementing a technical cycle system for C2C in their companies. Those companies that are already pursuing closed-loop supply chain methods seem to be very well equipped for the implementation of C2C standards. Elements of

closed-loop supply chains such as product characteristics or collections strategies can valuably enrich the perspective on a technical cycle for C2C products and hence make it easier to realize. Furthermore, the C2C cases offer an additional perspective for closed-loop supply chain theory by providing evidence from companies that are engaged in sustainability. Although direct as well as indirect economic gains are a major driver for C2C implementation, usually fundamental change processes are needed. Hence, support from the top management is decisive for success.

As the main findings of this research are based on the limited number of six cases, results need to be assessed carefully in order to draw conclusions for different settings. Especially as product characteristics seem to play a critical role influencing the design of closed-loop supply chains, further research is needed to verify these first findings presented. Hence, C2C products from different industries should be analyzed to generalize or differentiate our results. Furthermore, as we only provided an overview of critical factors, further research could provide important insights on certain details of C2C closed-loop supply chains, for example on collection strategies or recovery methods.

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