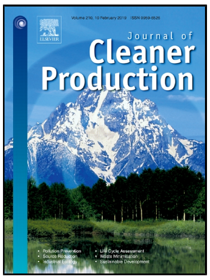

In Support of Open-Loop Supply Chains: Expanding the scope of environmental sustainability in reverse supply chains

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In Support of Open-Loop Supply Chains:

Expanding the scope of environmental sustainability in reverse supply chains

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Abstract

This study expands the environmental sustainability paradigm of reverse supply chains. The study examines the notion of closed-loop supply chains and suggests the use of the term in academia and business is too limited from a sustainability perspective. Three case examples in automotive remanufacturing were chosen to represent a global, multi-tier industry with documented circular economy strategies. A simple conceptual framework is developed that bridges different concepts of "loops" at whole product, component and material levels, and which is then used to show that closed-loop supply chains that focus on OEM activities appear to overlook alternative models of reverse supply chain loops. The study considers how these alternative loops contribute to environmental sustainability by looking at market dynamics and relations between business actors in supply chains in automotive remanufacturing. Alternative loops may contribute to product displacement activities in the market and thus provide positive environmental and resource results. The narrow focus on "closed loops" in supply-chain research and industry simplifies potential benefits and weaknesses, and overlooks the contribution of

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“open loops” in supply chains, which enable business innovation and can improve sustainability outcomes in product and material supply chains. This article fills a void in supply chain management research and argues for a more adaptive management approach to reverse supply chains for end-of-life products.

Keywords: closed-loop supply chains; sustainable supply chain management; industrial ecology; circular economy; remanufacturing; recycling

1 Introduction

Remanufacturing is an important industry that is receiving new attention in circular economy discussions (USEPA, 2016). In the largest remanufacturing nation, the USA, remanufacturing was valued at USD 43 billion in 2011 (USITC, 2012). Remanufacturing prolongs use of returned used components – so called “cores” – that undergo a manufacturing-like process of disassembly, cleaning, part replacement, assembly and testing including quality controls to provide a “good as new” product (APRA Europe, 2014; Lund, 1984) that sometimes exceeds the original conditions (USITC, 2012). Without remanufacturing, a new product would be necessary to fulfill the need. Although reuse is usually assumed to reduce environmental impacts (Lund, 1984), Cooper and Gutowski (2017) argue the sustainability of reuse activities depends on whether second use capitalizes on technological developments that reduce energy consumption during the use phase. Similarly, remanufacturing of automotive components leading to an extension of life of the product (e.g., the automobile) may not necessarily reduce overall energy consumption, for example, when a used vehicle emits more greenhouse gas over its extended lifetime than that of a new vehicle.

Previous research (Kalverkamp et al., 2017; Kalverkamp and Raabe, 2017) discovered that independent remanufacturers, especially those not tied to an original equipment manufacturer (OEM), will sometimes manage reverse supply chains (SCs) in a manner that is different than regularly suggested by literature or in innovative ways that increase longevity of the remanufactured components in ways not considered by OEMs. Prior research emphasis on OEMs as necessary for the success of closed-loop supply chains (CLSCs), and the general assumption that CLSCs, *de facto*, “are sustainable” (EMF, 2013) was put into question when interviewees identified situations that differed from the CLSC-concept in terms of market practices and product innovation.

This article aims to uncover this “missing link”. First, we review knowledge from two fields: supply chain management (SCM) and industrial ecology (IE), to look at the idea of “loops”. This is the first contribution of this study: the term “loops” has been widely used across both fields, though there appears to be a lack in the common understanding, leading to misconceptions of the environmental sustainability of material loops. We further explore these ideas using three cases of reverse supply chains in the automotive industry. In our results, we question the assumption that “closed loops” at the single firm level are the sole form of reverse supply-chains in an environmentally sustainable circular economy. Our results question whether the greater managerial advantage of OEMs over independent actors in CLSCs leads to better environmental outcomes. To reduce net environmental impacts, we conclude that it is most important: a) to displace primary production of raw materials; and, b) to innovate at the product level to improve performance and longevity. Both open loops and closed loops can achieve these objectives, therefore, we advocate for a more differentiated view on loops in supply chains.

2 Background

Closing the loop can occur at global, national, regional and local levels. Reverse supply chains can operate at the same scales as do production and distribution in forward supply chains. Hence, the question whether a loop is closed can hardly be answered *a priori* (Lyons 2007). Moreover, a company's motivation to close the loop may rely on business considerations rather than on resource sustainability (Stindt et al., 2016). For example, a company may utilize reverse logistics to establish entrance barriers to competitors that make use of the company's used products (Esty and Porter, 1998; Stindt et al., 2016). Therefore, such CLSCs may not actually reduce the environmental impact. However, a reverse SC system where a third party takes advantage of waste streams from forward SCs or from leakage from an OEM CLSC may achieve beneficial reuse, remanufacture or recycle. The complexity of closing loops from the product end-of-life or end-of-use can be seen from a life cycle management perspective. Reuse, recycling and recovery can be seen as a continuum of "cascade use", which entails implications for the management of according systems of SC loops (Kalverkamp et al., 2017).

Drawing from the literature in SCM and IE, supply-chain activities can be mapped at three levels: product, component and material (Figure 1). This framework served as a basis for our case selection (section 3 and 4). Our mapping considers the context of circular economy and environmental objectives. The product/component/material hierarchy emphasizes increasing value-added and economic utility, consistent with cradle-to-cradle (McDonough and Braungart, 2002) and eco-efficiency thinking (Young et al., 2001). It also aligns with the popular "circular economy system diagram" from the Ellen MacArthur Foundation that illustrates possibilities for enhanced flows of goods and services, covering both "technical and biological materials" (EMF, n.d.).

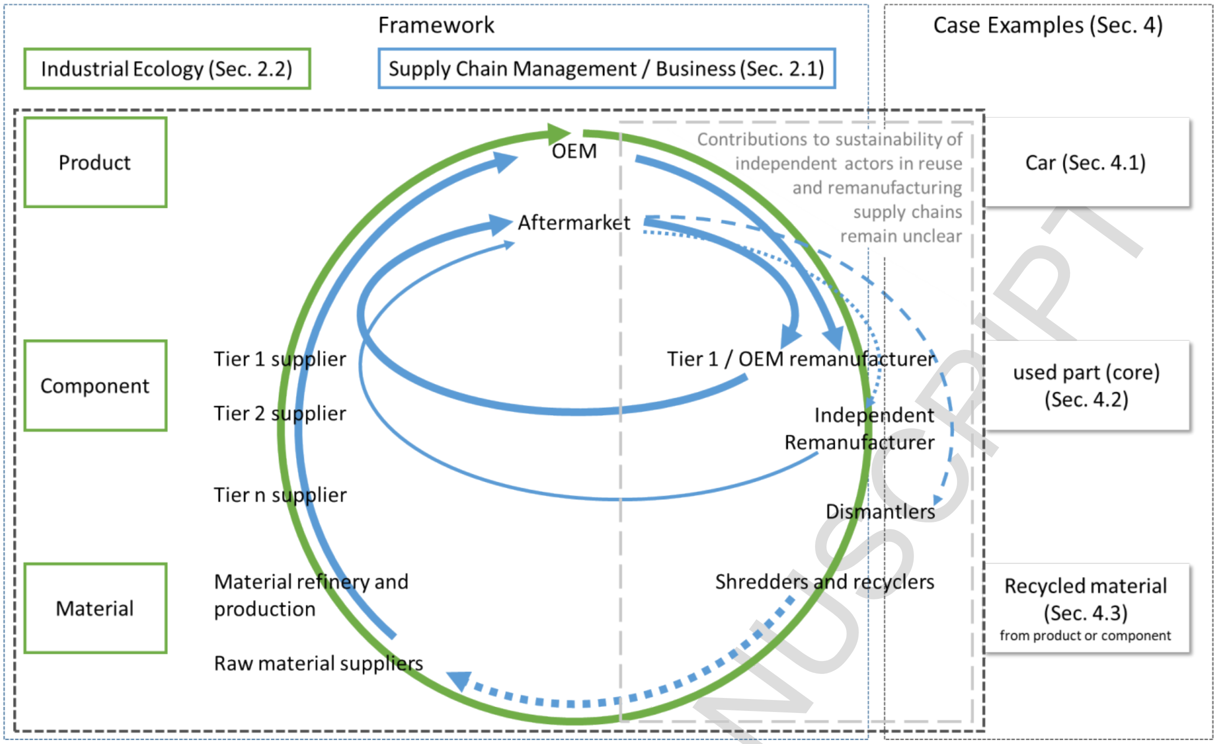


Figure 1: Framework for this research mapping actors involved in supply chains that close loops across the hierarchy from materials to components to products. Industrial ecology loops (in green) focus on physical cycles; whereas supply chain management loops (in blue) consider who are the business actors; the role of rather independent actors in reverse supply chains and their sustainability contribution remains unclear (research gap outlined in sec. 2.1; dashed grey box).

As can be seen in Figure 1, whereas industrial ecology emphasizes physical life-cycle loops, supply chain management focuses on business actors in production loops. Industrial ecology considers different scales, for example in life cycle assessment, at the product level and often focusing on material recycling loops in particular, with more recent attention to component remanufacturing (see for example the review by Cooper and Gutowski, 2017). For automotive systems, in supply chain management one focus is component remanufacturing SCs. Looking at the circular economy discussion, we find that the language of "closed-loops" is often favored (see for example Ellen MacArthur Foundation). In the sense of a state-of-the-art overview, the following sections elaborate on concepts of loops from the separate perspectives of supply chain management (SCM) (section 2.1) and industrial ecology (section 2.2). Thereby, these two sections also clarify the research gap as indicated in Figure 1 (grey dashed box on the right of the circle, i.e. the reverse part of the supply chain). We then draw lessons from these different perspectives (section 2.3).

2.1 Sustainable supply chain and closed-loop supply chain management

In production systems the flow of materials or products is perceived as forward oriented: towards the end-customer. However, loops in the SC are often presented as “reverse”, including feedback of information, include physical loops return products from the customers back to the OEMs, for warranty, repair, waste disposal, and recycling (Guide et al., 2003; Östlin et al., 2008). Reverse supply-chains are a key area of study for supply-chain sustainability. Sustainable supply chain management (SSCM) incorporates the “triple bottom line” into traditional SCM, although different approaches exist (Seuring and Müller, 2008). The CLSC approach complements SSCM by looking at reverse supply-chains (Brandenburg et al., 2014; Seuring, 2013).

A CLSC is commonly defined 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 types and volumes of returns over time” (Guide and van Wassenhove, 2009: 10). This perspective excludes, for example, secondary markets for retail goods, which could be considered in a “wider definition of closed-loop supply chain management” (Guide and van Wassenhove, 2009).

In general, CLSCs consider loops that go back to the same company, usually in an OEM-dominated SC network. Yet CLSCs are complex systems, which rely on reverse supply-chain operations with numbers of independent actors, which could be wholesalers, retailers, distributors or final customers. Therefore, the ability of one single actor to actually “control” the whole CLSC is limited (Guide and van Wassenhove, 2009). The term CLSC is further used to describe loops where third parties take advantage of returned or disposed products or components (Majumder and Groenevelt, 2001). Especially in remanufacturing SCs, independent remanufacturers take advantage of either OEM forward SCs or leakage from OEM CLSCs (Kim et al., 2010), for example, due to limitations in the product acquisition management (Abbey et al., 2015) or due to independent remanufacturers intercepting cores (Ferrer and Swaminathan, 2006; Saavedra et al., 2013). In some cases independent remanufacturers are contracted by OEMs to perform remanufacturing of components that the OEMs have retrieved and which remain OEM property throughout the remanufacturing process (Lind et al., 2014; Lund, 1984).

To reduce management efforts in CLSCs, leasing and renting business models have been developed to work without a transfer of ownership, and incentive-based approaches such as deposits to encourage the reversal of transfer of ownership. Such approaches and product service systems are commonly suggested in circular economy discussions (e.g. EMF, 2013). From a business model perspective, Agrawal et al. (2012) ask whether leasing is greener than selling and conclude that the assessment depends on the product's durability and its impact during the use phase. Furthermore, the size of secondary markets and product's utility value can influence the environmental impact of remanufacturing (Yalabik et al., 2014).

The complexity of CLSCs leads to optimization challenges, usually with a focus on the SC owner. This includes the optimization of return flows (Dutta et al., 2016; Kumar et al., 2017) and general improvements of network and production planning (Gaur et al., 2017; Polotski et al., 2017). Although some studies address competition in reverse channels (Ferguson and Toktay, 2006; Ferrer and Swaminathan, 2006; Majumder and Groenevelt, 2001), for example, competition between reverse channels to serve the OEM (Liu et al., 2017; Taleizadeh et al.,

2018) or regarding pricing of new versus (independently) remanufactured components (Abbey et al., 2015).

In our review, we did not identify CLSC studies focusing on independent competitors who operate as primary actors in reverse supply chains (part of the research gap as indicated in Figure 1). Typically, researchers aim to understand how OEMs can best manage competition by independent actors (e.g., through pricing, acquisition strategies, and business models). In more empirical studies, independent actors do come to the fore, though research has not necessarily focussed on their potential competition to the OEM but on their contribution to remanufacturing (e.g. Saavedra et al., 2013), independent actors in reverse SCs may be an important driver for OEMs to establish CLSCs for business reasons (Stindt et al., 2016). When the OEM does not consider closed-loop activities, independent actors operate in what Prahinski and Kocabasoglu (2006) referred to as "open-loop systems" in reverse SCs, whereas others have framed such independent activities outside OEM control as "business lost to unorganized sectors" (Bhattacharya et al., 2018).

CLSCs provide simultaneous opportunities for economic and environmental benefits (Difrancesco and Huchzermeier, 2015; Guide and van Wassenhove, 2009). Nonetheless, CLSC models focus mostly on financial optimization, which questions the common assumption that CLSCs are sustainable "by definition" (Quariguasi Frota Neto et al., 2010). Although a recent study on CLSC profitability merging the remanufacturing SC with the manufacturing of new SC to produce a "hybrid component" may provide ground for more environmental sustainability (Bhattacharya et al., 2018). Research has further considered factors such as energy use (Bazan et al., 2017) and LCA data into the CLSC model (Quariguasi Frota Neto et al., 2010; Sahebjamnia et al., 2018).

The term CLSC covers a wide range of different supply chain designs aiming at product (and component) recovery usually with the intention of value recovery. However, OEMs may further use CLSCs to corner markets hence to limit and control potential competition by independent remanufacturers (Ferguson and Toktay, 2006; Kalverkamp and Raabe, 2017; Lebreton, 2007). The latter provides an example where the primary purpose of CLSCs is the preservation of the market value of new products and not the value recovery from used products. Such practice may be relevant for OEMs, protecting their business interest, though not for independent remanufacturers depending on the supply of cores. This is one reason why the term CLSC in combination with the assumption of sustainability may be misleading as suggested by the research gap indicated in Figure 1. Alternative and complementing terminology may help to better distinguish between SC types and their contribution to sustainability. With the “open-loop system” (Prahinski and Kocabasoglu, 2006) in mind, the remainder of this section explores additional perceptions of loops and how they relate to SCM preparing for the examination of loops and their environmental sustainability potential in practice.

2.2 Loops in industrial ecology

In industrial ecology and life cycle assessment (LCA), material-loops are seen in physical terms; although recent critical-thinking in LCA research has incorporated more on market dynamics (Nilsson-Lindén et al., 2014). Several concepts from LCA relate to loops in SCs: inherent properties, functional recycling and displacement.

A significant literature has focused on environmental benefits of recycling; however, the same principles are relevant to remanufacturing. The international standards on LCA methods explicitly consider closed and open material loops (ISO 14044 2006; ISO 14049 2000) and refer to the notion of “inherent properties of materials” to distinguish modelled recycling modes. ISO defines situations where inherent properties are preserved as closed-looped recycling. Where inherent properties of materials are not maintained, the recycling is classified as open-loop. The idea of inherent properties translates to the idea of quality or value provided by materials (Dubreuil et al., 2010). However, the ISO definitions are not particularly clear and their interpretation continues to cause confusion regarding the costs and benefits of material recycling (see for example the comments of Geyer et al., 2016). A more useful concept is “functional recycling” (Graedel et al., 2011), which builds upon the idea of inherent properties introduced in the ISO standards. Functional recycling occurs when materials are recycled in a manner that retains their engineering characteristics and material properties. Notably, the overall levels of functional recycling of industrial materials is disappointing, with few material commodities exceeding a rate of 30% (Graedel et al., 2011).

Related to functional recycling is the idea of “displacement”, which refers to substitution of primary material by secondary material. Displacement is necessary for environmental and resource benefits to incur (Atherton, 2007; Dubreuil et al., 2010; Geyer et al., 2016; Weidema, 2017). Geyer et al. (2016) make three observations:

1. That environmental benefits are possible only if recycled material displaces primary material production,
2. That multiple recycling in a closed material loop is not, *per se*, environmentally beneficial,
3. That the distinction between closed- and open-loop material recycling is not helpful to environmental objectives.

We extend this thinking to suggest that displacement is just as important to other circular economy strategies like reuse of products, components and materials, and life-extension approaches like remanufacturing and repair. Importantly, factors that determine displacement are both physical and economic, and market dynamics in supply-chains are important and complex (Geyer et al., 2016; Weidema, 2017). Depending on market dynamics, negative environmental consequences might even arise as a market consequence of improved recycling or reuse activities: the "circular economy rebound" effect (Zink and Geyer, 2017) results whereby the full positive effects associated with recycling and reuse are not realized because there are increased levels of consumption and production.

2.3 Openness in supply chain loops

Our review of CLSCs shows product and material flows leaving CLSCs to independent third parties are understudied. There is little in the literature on the environmental sustainability of reverse logistics, other than for closed-loop supply chains. Because of the preference for closed production loops managed by OEMs who control product knowledge and market access, in CLSC research, the potential of SCs that close physical loops yet maintain business openness has been overlooked. Nonetheless, we observe that this activity in the market dynamics of automotive components that are reused, remanufactured, or sent for material recycling or recovery.

Based on our previous research (Kalverkamp et al., 2017; Kalverkamp and Raabe, 2017), SCs characterized by open ownership is driven by small independent remanufacturers that usually do not have contract-relationships with OEMs. However, these independent actors achieve process and product innovations that present potential for environmental benefits. They find their own core supplies and they innovate at the component-level, for example to increase product longevity (see case II; Kalverkamp et al., 2017; Kalverkamp and Raabe, 2017). Although previous research on independent remanufacturers exists, and in some areas these actors have substantial market shares, these firms are often relatively small, and occupy niches such as in automotive electronics or transmission remanufacturing (Weiland, 2012).

The limited focus of supply-chain research and industry on “closed loops” may be simplified due to degrees of freedom and willingness to participate and innovate in CLSCs. The understanding of loops in SCs and the potential contributions of independent actors to the circularity in the automobile industry drives this research. Thus: ***we hypothesise that independent business actors who control reverse supply-chains can achieve positive environmental outcomes through business and technology innovation.***

Thus, we are interested whether different concepts of loops in SCs make a difference, and if so, whom their main actors are, and eventually, whether such SCs provide additional opportunities for innovation and sustainable outcomes. Our study looks at market dynamics and relations especially between independent business actors. We seek to understand how SCs of independent remanufacturers and other independent actors may contribute to product displacement activities in the market to provide positive environmental and resource results.

3 Methodology

We employed an explorative, mixed-methods research approach with elements of grounded theory to examine loops in SCs. Three exemplary cases are used to examine the gap at each of the three levels of product, component, and material (see Figure 1). Each case is based on a site visit and focal interviews with representatives of the corresponding business. The case at the product level is an exception because in automotive remanufacturing, the core is usually a component and not the entire product (specific characteristics are explained in the respective sections).

For this study, the cases were selected so that each represents one level of the outlined product-component-material hierarchy (see Figure 1). The empirical data for the first case derives from a novel interview and side visit conducted in 2015. The interview data for the remaining two cases derives from previous studies covering a total of 39 interviews with experts and practitioners, side visits at remanufacturing companies, auto dismantlers/recyclers, and core brokers, to study SC practices in automotive remanufacturing more comprehensively (Kalverkamp, 2018; Kalverkamp et al., 2017; Kalverkamp and Raabe, 2017). Interviewees were usually involved in the management and operations of the supply chain of cores. Open-ended questions covered several themes such as the market for used parts, i.e. cores, and spare part availability, stakeholder influence (such as by direct and indirect competitors in remanufacturing and dismantling), and impacts of digitalisation, amongst others. For the previous studies, these interview data were coded and clustered. Both raw data and processed data were consulted again for this study to deduct findings about the design of component loops in automotive remanufacturing. In total, this resulted in five case-specific interviews and three side visits for the basis of the cases; the entire interview data provides valuable background and contextual information on the cases. Interviewees and company names are anonymous.

To test our hypothesis, we focused on three research questions when looking at the cases. These questions address the research gap identified in section 2 regarding the perspective on loops, the role of independent actors in reverse supply chains and the environmental sustainability potential of "alternative loops":

1. What manifestations of reverse supply-chain "loops" in SCs can be identified at product, component and material levels?

2. What related differences emerge regarding SCs separate from OEM control, changing market context and innovation when comparing more independent SCs to “typical” CLSCs?
3. Are “loops” controlled by independent actors favourable from an environmental perspective?

In each of our three cases we employed a conceptual environmental assessment based on the framework provided by Cooper and Gutowski (2017) to illustrate the potential resource and environmental impacts across the life cycle. Although this is not a life cycle assessment, the results provide an approximate assessment of the environmental impact across the life cycle of the product or material. Reuse comprises both the impacts caused by processing and by re-using an item for an additional time; this assessment further considers whether products are powered (e.g. passenger cars) or unpowered (e.g. clothes) (Cooper and Gutowski, 2017). For this study, this differentiation needs to be carefully evaluated because also unpowered spare parts facilitate the life extension of the powered product, i.e. the passenger car.

Our cases look at remanufacturing in the modern automotive sector. This industry is global, relies on structured multi-tier forward supply-chains run by strong OEM companies, and has developed effective end-of-life management systems including recycling. The automotive industry today is particularly high-profile in circular economy strategies (see for example USEPA 2016), partly because the sector already achieves high levels of end-of-life product recovery, there is significant remanufacturing of automotive components conducted by OEMs, contracted and independent remanufacturers, and the majority of original materials are efficiently recycled. Sustainability considerations in this domain mostly focus on closed-loop supply chains at the levels of products and components (c.f. section 2.1). At the material level, both closed- or open-loops are discussed though mostly with respect to the environmental assessment and regarding rebounds, for example, due to market dynamics (c.f. section 2.2; considerations not further discussed here are the feasibility of recycling technologies and environmental regulations). With reference to Figure 1, the three cases cover SCs dominated by independent business actors and draw attention to both physical flows and business actors, and to the interaction of market and supply-chain complexities. By taking this perspective, the cases expand the scope of environmental sustainability in reverse supply chains in the automotive domain.

4 Results: examples of loops in automotive remanufacturing

4.1 CASE 1 - Reuse of products: product life extension through vehicle conversion

This case highlights the unpredictability of globally intertwined SCs and their environmental impacts by looking at a used-vehicle export from Japan to Chile. In large automotive markets in developed countries, numerous used vehicles are recycled or reused in local or export markets. Japan, in contrast to the US, Canada and the EU, does not have a culture that supports significant second-use within the country (Zaun and Singer, 2004). Japan is estimated to export approximately 1 million cars per year (Kumar and Yamaoka, 2007), and most of these vehicles are approx. only 6-7 years old (some only 4 years according to local sources) hence having considerable useful life remaining. With a transfer of ownership, vehicle reuse regularly occurs in forward SCs, also from CLSCs based on leasing vehicles are often resold (Lacourbe, 2016). In either case, the transfer of ownership may result in exporting into a different region, which involves different legal obligations and different repair and recycling infrastructure.

In 2015, the top 10 countries importing right-hand drive used-vehicles from Japan included the “left-hand drive” countries United Arab Emirates and Chile (JEVIC, 2015). We investigated the case of Chile in more detail to understand the fate of those right-hand drive vehicles. The northern city of Iquique hosts the free trade zone ZOFRI – Zona Franca de Iquique (ZOFRI, 2017). Low trade costs at ZOFRI, combined with a general demand for low-cost private transport in the region (including Peru, Bolivia and Paraguay), foster the demand for used-vehicle imports. In the port’s direct vicinity, we located small “cambio volante” workshops where mechanics convert vehicles from right-hand drive to left-hand drive. Figure 2 shows two steps of the conversion process. This situation may raise concerns, such as safety of converted vehicles. Notably Japanese exporters provide conversion kits or full conversion services conducted in Japan before export (e.g., www.japan-partner.com/LHD-conversion.php), which indicates some formality in the conversion process.

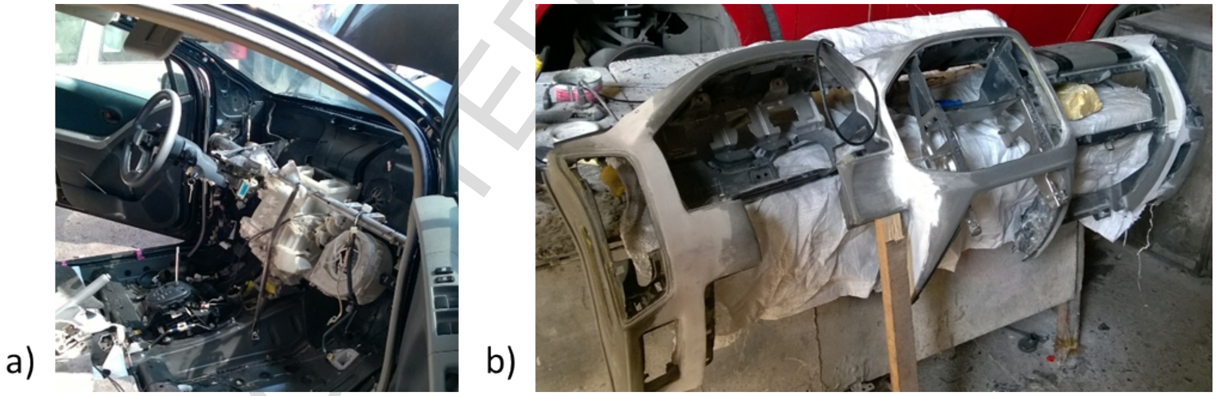


Figure 2: (a) Converted cabin of a former right-hand drive; (b) converted dashboard before receiving new PVC coating (pictures taken by the authors).

Vehicle reuse has potential for resource and value preservation. The combination of materials in the final product, together with invested labor, time and energy mark the value preservation potential of reused vehicles (Östlin et al., 2009). An extended product lifetime may displace the production of new products. However, there are limits to the displacement potential and vehicle reuse may cause net negative effects on the environment, as it extends the life of outdated technology.

Our assessment of the environmental burden considers average lifetimes and mileage of the vehicle as well as the burdens of production and recycling. If the vehicle has not yet reached the average mileage where the environmental burden of an extended usage is greater than the production and use of a new vehicle, ten years according to Skelton and Allwood (2013), reuse should lower the environmental burden due to the displacement of virgin production. For the Japanese car, this optimal length would likely require a second use. However, LCA studies on life-extensions of vehicles regularly conclude that there is no clear indicator for when the environmental impact of production and usage of a new vehicle is lower than an extended usage (e.g., Kagawa et al., 2011; Spielmann and Althaus, 2007), as this depends on different technological development (e.g. fuel efficiency), availability of recycling technologies, and user behavior. For products with a high rate of innovation, despite the burden of material and manufacturing, it may be desirable to have a shorter turnover that does not delay upgrading to cleaner technologies (Allwood et al., 2012).

Reuse of younger vehicles is reasonable from an environmental and an economic perspective. The export of vehicles may provide additional life cycles, displacing older vehicles in the importing countries with newer technology. However, the contribution by exports to a lower environmental burden is limited due to potentially growing vehicle fleets in countries receiving used vehicles (Davis and Kahn, 2010) and to a lack of recycling infrastructure (Hagelüken, 2007). In the case of vehicle exports from Japan to Chile, the "cambio volante" SC provides the opportunity to reach the ideal lifetime. Figure 3 depicts a conceptual environmental assessment for the Chilean case and shows how life extension could improve the environmental footprint. However, excessive supply and poor recycling infrastructure in Chile limit the environmental benefit.

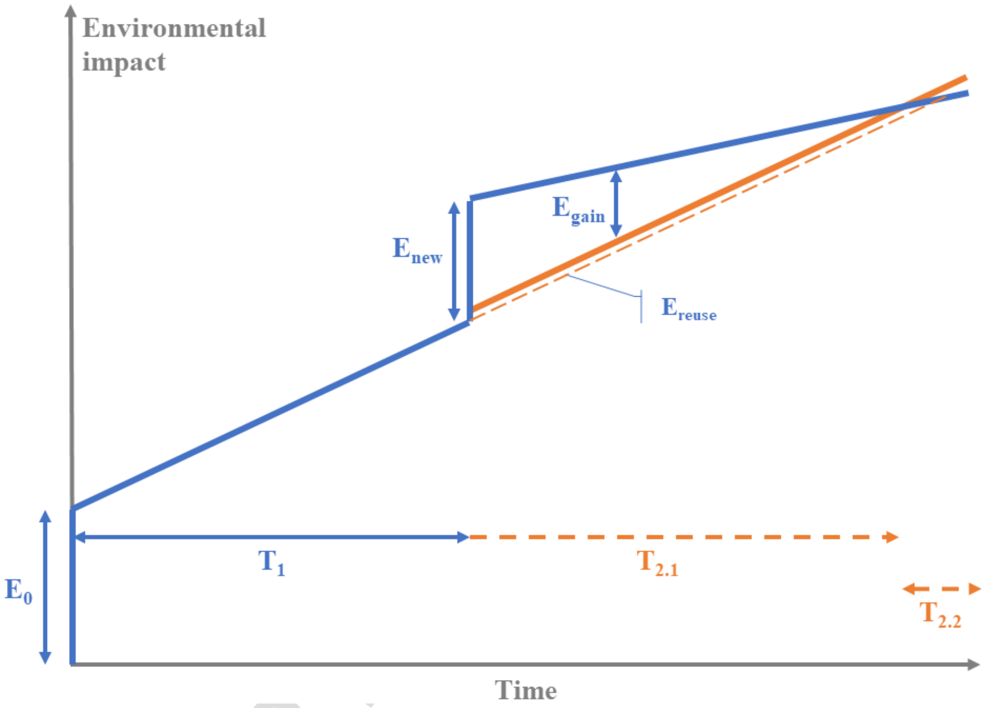


Figure 3: Environmental assessment of the vehicle reuse in the Chilean "cambio volante" case (adopted from Cooper and Gutowski, 2017). The difference between the dashed and the solid orange lines indicate the additional environmental burden due to transportation and conversion; the distance between the orange and the blue line above $T_{2.1}$ *indicates the net reduction of environmental burden due to displacement. Blue: time or energy inputs of new product; orange: time or energy input during reuse;* $E_{0/new}$ *= initial/new vehicle environmental burden;* E_{reuse} *= reuse in Chile;* E_{gain} *= net reduction of environmental burden;* T_x *= use phase/s;* T_1 *= vehicle lifetime in Japan;* $T_{2.1}$ *= vehicle reuse lifetime in Chile (ideal);* $T_{2.2}$ *= lifetime in Chile exceeding the ideal;* $T_{ideal} = T_1+T_{2.1}$ *(e.g., ten years).*

4.2 CASE 2 - Remanufacturing of components: automotive parts

This case addresses reuse at the component level of a vehicle, which extends the lifetime of the entire vehicle including other still usable parts (Quantis, 2013). Reuse of automotive components is widely practiced in the industry. Vehicle dismantlers remove and sell components for direct reuse “as is”. In some countries, collision shops repair vehicles with reused parts. In North America, “interchange systems” facilitate reuse by supporting repair shops with databases that identifying interchangeable auto parts (Kalverkamp, 2018).

In contrast to direct reuse, automotive remanufacturing focusses on mechanical, mechatronic and electronic components, estimated in the US with a market size of USD 7.1 billion in 2011 (USITC, 2012), which is more than double the corresponding market in the EU (Weiland, 2012). Notably, remanufacturing can improve original component design (e.g., ERN, 2015; USITC, 2012 for automotive components, or Cooper and Gutowski, 2017 more generally).

Direct reuse and remanufacturing loops can be established at dismantling facilities or by remanufacturers who establish reverse logistics in order to circulate cores (Östlin et al., 2008). Even OEMs require supply from independent SC actors because the number of returns and the yield from their immediate CLSCs is usually insufficient for the targeted outputs (Saavedra et al., 2013).

Our case examines an independent remanufacturer who takes advantage of cores supplied through dismantling SCs to support its CLSC. The market for electronics and mechatronics remanufacturing is rapidly growing and currently independent remanufacturers seem to dominate the market. Figure 4 shows the loops for the case as an excerpt from Figure 1. Authorized repair shops are supposed to return exchanged electronic control units to the OEM, although the OEM does not remanufacture these components. The OEM uses component exchange as a control mechanism to prevent reuse or remanufacturing. In addition, we learned from our set of interviews that OEMs are usually not interested in improving product design through remanufacturing, for example in the case of contracted remanufacturing.

Market dynamics created by customers seeking alternatives to high-priced OEM spare parts together with SC loops initiated in the aftermarket set the stage for innovation by independent market actors. The green arrows in Figure 4 highlight transfers of ownership to the independent remanufacturer who is central to the loop. The studied independent automotive remanufacturer regularly remanufactures on a “same part” basis, essentially running its own CLSC, which means that each customer’s faulty component returns to the same customer. Such one-on-one exchange is often necessary because OEMs program mechatronic and electronic components to be used in one particular vehicle only. The remanufacturer provides other components on an exchange basis, and some of these components need reprogramming by an OEM-authorized dealership after installation. Thus, the remanufacturer combines supply from the open-loop system with the exchange system which corresponds to the typical CLSC.

The remanufacturer also exploits weaknesses in OEM components, which the remanufacturer addresses with improved designs. For example, in the case of a regularly malfunctioning throttle body, the remanufacturer replaced a potentiometer that is used as a position sensor in the throttle body with a Hall-effect sensor. The remanufacturer claims that this change increases the longevity of the throttle body due to less wear and tear. Other such examples were presented and also the case that an OEM wasn’t interested in implementing such longevity improvements through contracted remanufacturing.

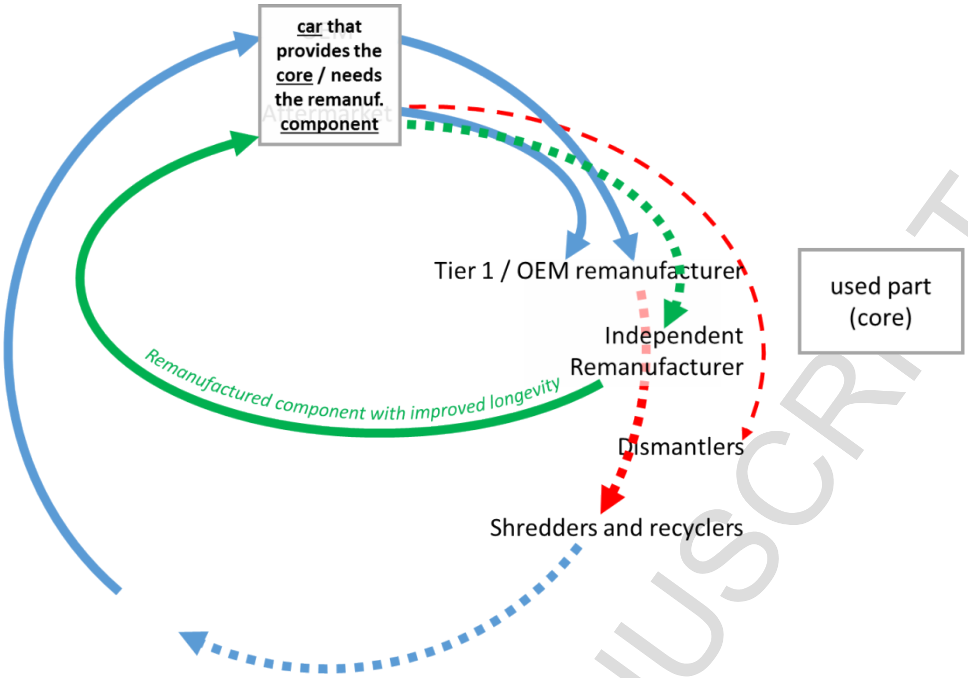


Figure 4: A component remanufacturer establishes a closed-loop supply chain from the original supply chain hence enables an alternative closed-loop (green loop). Sometimes reverse logistics are used to prevent loops from being closed at the product or component level (red and blue loops).

This remanufacturing case shows once again that the potential for resource and value preservation is not limited to CLSCs controlled by OEMs. A life extension through remanufacturing is not necessarily environmental friendly per se, nor is it generally better than recycling. This was illustrated for remanufacturing an old diesel engine compared to a new engine complying with higher emission standards (Zhang and Chen 2015), and in line with Cooper and Gutowski’s (2017) general findings on reuse and remanufacturing. The example of remanufactured diesel engines highlights the case-by-case analysis that is needed, and for vehicles that the full assessment of production and use phases (and reuse and recycling phases) is important. For the remanufactured throttle body, our analysis suggests a more sustainable life extension. This phenomenon has the distinct potential to displace new vehicles sales and virgin raw material production.

Based on this logic, Figure 5 depicts the environmental impact for the presented case of the mechatronic vehicle component that is improved through remanufacturing. Although limited to specific types of components this case highlights the potential of remanufacturing by independent actors to increase longevity through innovation. At some point, however, it may be better from an environmental perspective to replace the entire vehicle due to technology improvements that lower the environmental impact substantially.

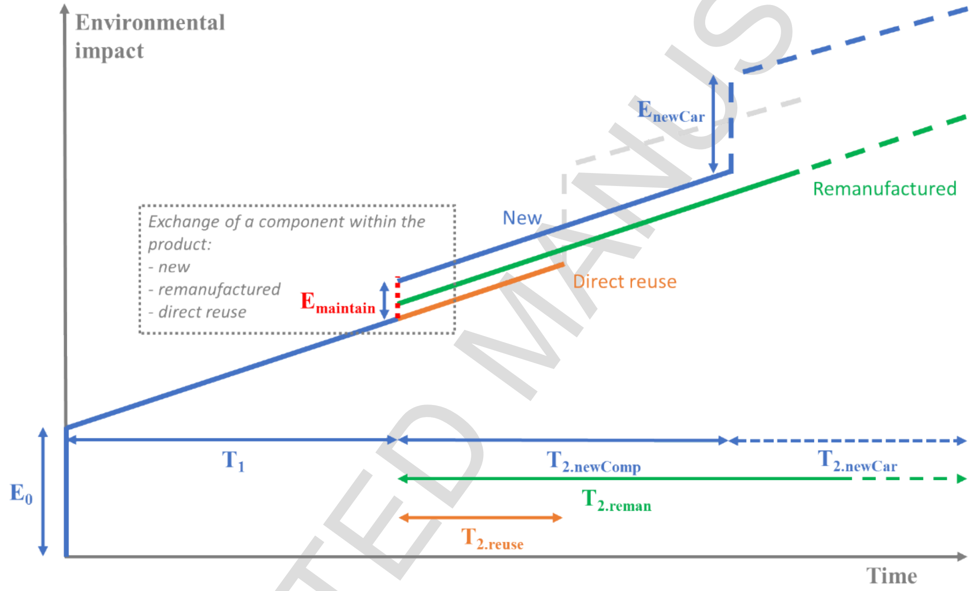


Figure 5: Environmental assessment of automotive component remanufacturing with improvements on the longevity of the component (adopted from Cooper and Gutowski, 2017). The customer has three replacements options for maintenance: direct reuse, remanufactured, or new component, each with different lifespans $T_{2.x}$*, namely* $T_{2.reuse}$*;* $T_{2.reman}$*;* $T_{2.newComp}$*. Direct reuse leads to the lowest additional environmental impact, though a direct-reuse component is more likely to fail earlier than a remanufactured or new component. Therefore, a replacement of the entire vehicle may happen earlier than in other scenarios (orange and dashed grey lines). The remanufactured component starts with a higher environmental impact than a direct reuse due to additional material and energy inputs, though the remanufactured component has a better longevity and therefore displaces the vehicle replacement further into the future (green lines) than a new component (blue lines).*

4.3 CASE 3 - Recycling of material: Copper and the competition between reuse and recycling

This case looks at how SCs for component reuse and material recycling intersect (see Figure 1), using the case of copper recycling from alternators. Business practices and legal requirements foster different recycling routes in different regions (see case 1). Car producers in the EU are responsible to provide take-back infrastructure for end-of-life vehicles and vehicle recycling must reach defined quotas (EU, 2000). Raw material prices are an important driver for the recycling of vehicles. Usually, dismantlers received higher prices for a component that is sold through a broker for reuse than for scrap for recycling. However, if there are high raw material prices or high costs for remanufacturing, prices for both cores and scrap metals may reach similar levels.

Alternators are car components with a high content of copper, a metal that reaches high yields in recycling (Graedel et al., 2011). Between December 2010 and July/August 2011 copper prices reached an all-time high. As shown in Figure 6 the daily spot price for primary copper spiked above USD 10,000 per metric ton (LME, n.d.), resulting in direct price competition between the core and its copper value. However, according to recycling experts, the prices for secondary copper depend also on the individual recycler.

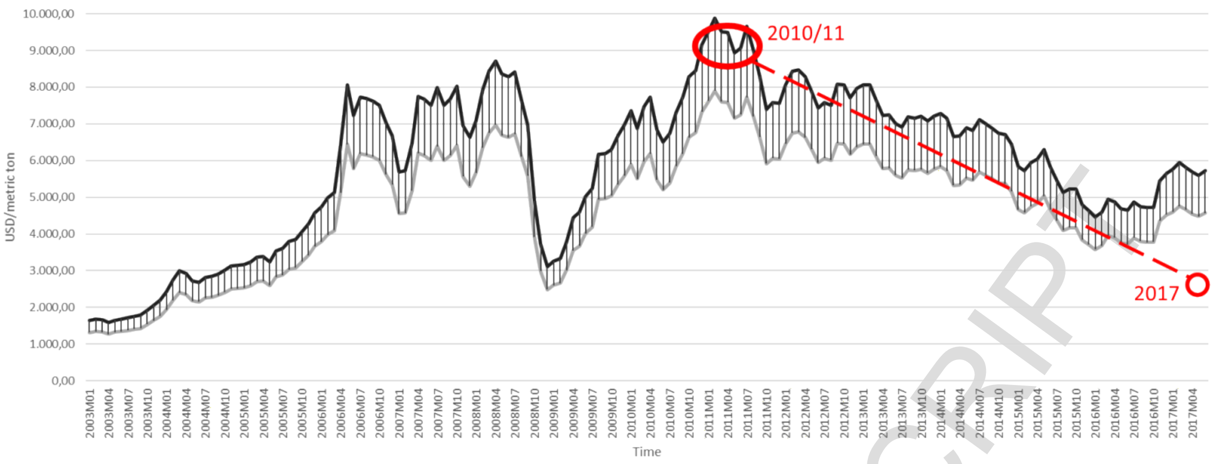


Figure 6: Monthly copper price in USD per metric ton (2003 - June 2017), black line shows virgin metal price, grey line is 80% and represents lower end of a price range for good quality copper scrap. The red circles indicate the estimated price offered for the copper content in sorted alternators (copper price data from the IMF: www.imf.org/en/data; scrap price 2011 from interview and 2017 from http://www.computerplatinen.de and http://www.schrottankauf-bitterfelderstr23.de).

During the peak of primary copper prices, remanufacturers experienced pressures from competing buyers. Based on expert knowledge, we estimate that an average alternator weighs 5.5 kg and contains 0.7 kg of copper. In 2011, when the copper prices were at their peak, a ton of sorted alternator scrap reached approx. EUR 800 (or USD 1100), approx. EUR 4.4 per alternator core. From a bin of alternators, which are not further separated by make or model, one alternator core is worth EUR 4.5-5.00. Prices for alternators vary, though an unsorted mix of alternators has much less value for a remanufacturer than for a material recycler. Therefore, when the prices for cores and for scrap metal reached similar price levels, dismantlers may have sold to customers that have lower requirements regarding the degree of component separation, and therefore lower cost to the dismantler.

Despite some uncertainties in the data, such prices for used alternators would have challenged core brokers. Nevertheless, according to the interviewee, dismantlers and other potential suppliers had difficulties to collect the necessary amounts of alternator scrap. The interviewee did not see a longer influence of the copper price on the company's business with dismantlers as core suppliers. The reason for this low impact may be rooted in the relatively short period the copper price remained above 9,000 USD per ton. Nevertheless, the interviewee mentioned that buyer competition due to both raw material prices and a different estimation of the residual value does influence the sales decisions of the dismantlers. Besides material recyclers and remanufacturers, buyers that are interested in cores that can be sold as "repairable" parts (e.g. to developing regions) further influence the buyer's competition hence add to the market dynamics.

The case of alternators indicates that the potential for resource and value preservation does not necessarily correlate with the environmental effects of according "loops". In this case, the perspective changes from the product and component level to the material level, which affects the perspective on the environmental assessment.

On the one hand, CLSCs provide good opportunities to generate necessary amounts of used products that can then be reused or recycled. On the other hand, once vehicles reach a recycling SC, the actors are typically independent and therefore decide individually whether the recycling route will be an open- or closed cycle. Figure 7 depicts the environmental assessment at the level of material recycling for the situation where a decision for recycling would be a decision against remanufacturing. Although any decision at the material level may displace primary production of materials, if the material-containing component is remanufactured, the displacement effect may be much greater than with recycling due to the displaced production of a new component and the additionally displaced material from the product whose lifetime is extended. Again, the assessment at this level depends on the effects on the whole product and hence is case-dependent. Therefore, the independent decision making at this point may be better than the attempt to define and enforce particular recycling (or remanufacturing) routes.

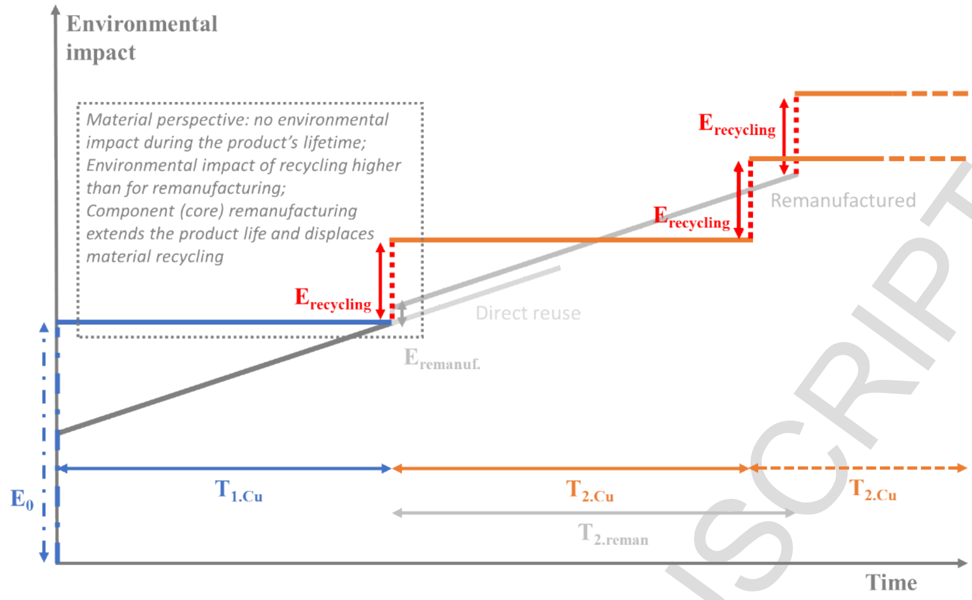


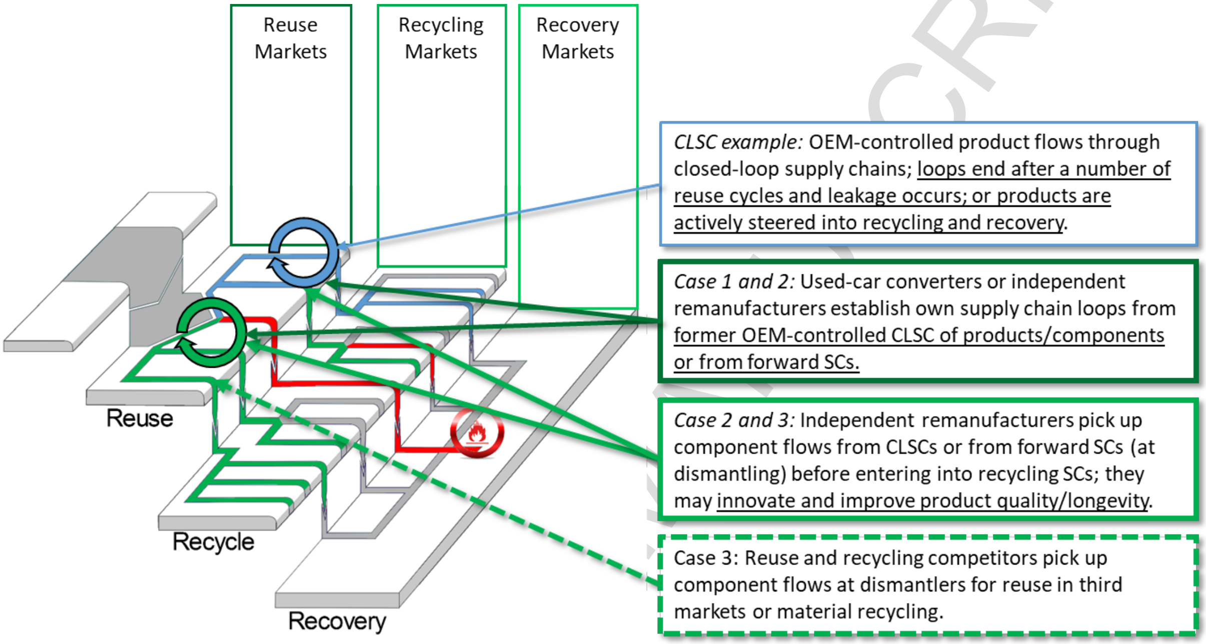
Figure 7: Environmental assessment of material recycling which increases the longevity of the material though remanufacturing would displace the environmental impact of material recycling (adopted from Cooper and Gutowski, 2017). Most outputs from automotive recycling enter open material cycles; e.g., functionally recycled copper from alternators is most likely used in many different products hence may contribute to very different displacement effects based on the newly produced product. The colored arrows depict the material perspective; the greyish lines in the background depict the reuse and remanufacturing perspective. E_x *= different "re"-options:* $E_{recycling}$ *= energy input for alternator/copper recycling;* $E_{remanuf.}$ *= energy input for alternator remanufacturing.* $T_{x.Cu}$ *= lifetime of copper in a product/component;* $T_{2.reman}$ *= lifetime of the remanufactured alternator incorporating the copper.*

5 Discussion

This study asked whether "closed-loops" are essential for a sustainable circular economy and whether a more distinct consideration of independent actors in the context of loops in SCs is reasonable. Specifically, we hypothesised that independent business actors who control reverse supply-chains can achieve positive environmental outcomes through business and technology innovation. In answer to our first question on the manifestations of "loops" in SCs, we found in all three cases that an independent remanufacturer can establish its own reverse SC loops. In these cases, products do not return towards the OEM but instead toward the independent remanufacturer who maintains control in a more open production loop. In literature, also reverse SCs of independent actors are considered under the term CLSC, although many studies have an explicit or implicit focus on the OEM as the central actor serving as the reference point for improvements and management decisions in the context of loops. Furthermore, the CLSC in the stricter sense implicitly focusses on the OEM as the central actor as it covers “design, control, and operation of a system … over the entire life cycle …” (Guide and van Wassenhove, 2009: 10). In contrast, an independent remanufacturer is not involved in the initial design of the product lifecycle hence can hardly establish a CLSC in this strict sense.

Following the observations made, and in answer to our second research question on the market context and innovation in independent SCs, independent and OEM-controlled reverse SCs often co-exist and may complement each other. For example, when OEMs compete with independent actors through remanufacturing or solely to maintain control over resources, or when cores are supplied stemming from the SC for vehicle dismantling. In the latter case, market dynamics affect the dismantling decision and sales of cores much more than in a leasing- or deposit-based reverse SC. However, some independent remanufacturers may rely on innovations in their former deposit-based reverse SCs to overcome barriers created by OEM-dominated CLSCs (Kalverkamp and Raabe, 2017). These differences may make it reasonable to have a complementing terminology differentiating SC types that close loops though with different characteristics of the actors and motivations involved.

Figure 8 presents the three cases using the “cascade use” framework (Kalverkamp et al., 2017) and illustrates that independent actors and corresponding supply chains provide more opportunities for business and innovation to advance reuse (and recycling). Results show that these SCs of independent actors have the potential to displace primary production and thereby to reduce environmental impacts. This challenges the established assumption that CLSCs, per se, are the preferred model for SC sustainability. This finding is in line with current research in the industrial ecology community on recycling (Zink and Geyer, 2017). We emphasize that a case-by-case analysis is needed, as asserted previously (Agrawal et al., 2012) and requires both physical and market factors in the assessment (Yalabik et al., 2014). In fact, the literature suggests that environmental rebounds might occur resulting in unproductive looping (Skene, 2017; Zink and Geyer, 2017).



CLSC example: OEM-controlled product flows through closed-loop supply chains; loops end after a number of reuse cycles and leakage occurs; or products are actively steered into recycling and recovery.

Case 1 and 2: Used-car converters or independent remanufacturers establish own supply chain loops from former OEM-controlled CLSC of products/components or from forward SCs.

Case 2 and 3: Independent remanufacturers pick up component flows from CLSCs or from forward SCs (at dismantling) before entering into recycling SCs; they may innovate and improve product quality/longevity.

Case 3: Reuse and recycling competitors pick up component flows at dismantlers for reuse in third markets or material recycling.

Figure 8: Open- and closed -loop supply chains and the complexity at the end-of-life of products or components (adopted from Kalverkamp et al., 2017).

In terms of the environmental impacts, and related to our third research question on “loops” controlled by independent actors, we suggest that SC models extending the perspective on CLSCs provide significant opportunity for business innovations and technological improvements, which in turn can provide lower environmental impacts. Due to the managerial oversight provided with CLSCs, including fewer intermediary actors and more direct supply routes compared to OLSCs, the CLSC model has perceived sustainability advantages—and is widely advocated (Difrancesco and Huchzermeier, 2015; EMF, 2013; Guide and van Wassenhove, 2009). However, independent remanufacturers, compared to OEMs, seem to have a stronger motivation to improve remanufactured components and structure innovative market relationships. The focus on CLSCs ideally driven by OEMs because of their product knowledge and SC power is actually irrelevant to sustainability.

Some independent actors take advantage of forward SCs and leakage from traditional CLSCs to seize control of close loops that reduce environmental impacts. However, especially the motivation for product innovation during remanufacturing at the component level seems to relate negatively to the OEM-dependency of the involved actors. In addition, the corresponding SCs can result in better sustainability outcomes than an OEM-driven CLSC (especially if the CLSC is meant to corner markets). Therefore, we argue for a complementing terminology to distinguish different types of reverse SCs: the open-loop supply chain. This differentiation does not cover the environmental benefit of the SC though it allows distinguishing which of the SC types provides greater environmental gains.

An open-loop supply chain (OLSC) arises where the original company loses business control of its components after sale, yet the component is still “looped” back to an independent remanufacturer for resale. OLSCs look like CLSCs except that the business involvement of main actors remains open to the market. Third parties are integral to OLSCs and have more discretion to participate than actors in CLSCs. Open-loops allow independent actors to innovate and to adopt alternative reuse and recycling strategies; the production (remanufacturing) is open to independent actors taking advantage of such open-loops. Thus, we propose that an OLSC is a “system that maximizes value creation over the entire life cycle of a product including (re-)design, where the control and operation of the system, particularly reverse logistics and the remanufacturing process, is conducted by a diversity of business actors other than the OEM”. By drawing the concept of an OLSC, this studies contributes to theory and the discussion in researcher on supply chain sustainability. Furthermore, the theoretical concept of an OLSC can help to develop more adaptive managerial approaches that respond to market forces, thus extending the established emphasis on OEMs in CLSCs.

Our results contribute to literature and to the understanding of environmental considerations in closed-loop concepts. Hence, they have implications for policy. From a policy perspective, the assumption of CLSCs being sustainable *per se* may lead to an underestimation of the contributions of actors supporting OLSCs. Policy makers should consider the role of (smaller) “independent” firms and carefully evaluate alternatives to mechanisms that favor OEMs or OEM-related actors. For example, policy makers should be cautious about taxes or subsidies that would benefit closed production loops because these overlook the equivalent sustainability potential of open-loop systems and may hinder significant market opportunities. Legislation should be designed to facilitate sustainability contributions regardless of particular business models. For example, legislation that facilitates reused parts in accident repairs may help the environment more than vehicle recycling quotas (such as in the EU) which aim to prevent material leakage though are difficult to enforce.

This study contributes to the industry perspective since it entails managerial implications. The results may motivate companies to investigate the contributions of independent third parties to the overall SC. Concern that OEMs might limit participation of independent remanufacturers (Esty and Porter, 1998; Stindt et al., 2016) reinforces competitive behavior (Ferguson and Toktay, 2006), where biased business objectives may constrain sustainability benefits (Quariguasi Frota Neto et al., 2010). Using OLSCs, OEMs might identify ways to benefit from product improvements and open innovations. Well-designed and competitive licenses for reuse or remanufacturing of OEM products and components in third markets may develop a long-term demand without the necessity to establish entire sales networks. Intellectual property rights already limit some reuse and remanufacturing, and OEMs should consider “open intellectual property” approaches that support broader sustainability objectives. Such considerations need further research and investigation to understand how businesses can balance impacts on themselves as well as environmental impacts. More proximately applicable are solutions such as the interchange systems for vehicle parts, as used in North America, that contribute to the efficiency of OLSCs to better match supply and demand between dismantlers and remanufacturers (Kalverkamp, 2018). Other industries and regions should look to and benefit from such solutions. Similarly, best practices from different industries may help to increase the efficiency of OLSCs and provide further study grounds as well.

The main limitation of this study is that product reuse itself is limited in practice; therefore, the body of knowledge is restricted and thus demands careful examination be generalizations can be mace. The cases examined are each limited to their own scope, and together may not be sufficiently representative for the general arguments made. We modestly suggest that the industrial ecology community is essential in supporting a “paradigm shift” to accept open loops. The SCM research community is in a better position to advance and implement OLSCs in ways that are sensible to business. We encourage research in sustainable and closed-loop SCM, in related product lifecycle management, in LCA on OLSCs hence with a focus on independent actors.

The study’s contributions indicate future research directions. From a theoretical perspective, the industrial ecology and supply chain management communities may cooperate and exchange ideas. With regard to markets and policy, further research potential lies in the complexity of interdependencies between legislation and market dynamics with the particular focus on the circular economy. Finally, not only industry but also research may benefit from a better understanding of how particular actors can benefit from more efficient activities through OLSCs.

6 Concluding Remarks

We identified commonalities and differences in the idea of “closed-loops” between SCM and industrial ecology, to address our research objective. To explore the emphasis on CLSCs in SCM literature, we analysed three cases wherein independent actors control both physical flows and contribute to environmental sustainability by displacing primary production through product or component remanufacturing; sometimes accompanied by innovation at the component level. The cases demonstrated that market dynamics and innovations of independent actors create loops outside the immediate OEM control.

The cases have shown that “open-loop supply chains”, which are open to a diversity of business actors, may have certain market advantages and can provide sustainable outcomes. However, independent third parties involved in OLSCs may not be considered in CLSCs due to the system boundaries. Considering these third parties by extending the managerial perspective of CLSCs may further reduce the negative environmental impact of closed-loops. The motivation for innovation by independent actors indicates that sustainability improvements may require OLSCs facilitating the transfer of ownership outside of OEM-controlled CLSCs. While acknowledging the managerial potential of the CLSC, SCM should treat the OLSC and the CLSC equally when it comes to sustainability assessments.

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