Understanding barriers to circular economy: cases from the manufacturing industry

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Received 13 February 2019
Revised 12 May 2019
11 August 2019
Accepted 14 October 2019

Abstract

Purpose – Most companies include a commitment for sustainable growth involving a switch towards the circular economy (CE) model. The purpose of this paper is to present barriers to CE adoption identified by a literature review. The paper also addresses the particular challenges faced by manufacturers by answering the research question: What are the dominant barriers faced by the manufacturing industry in moving towards a CE?

Design/methodology/approach – This paper presents a literature review of research identifying barriers for adopting to CE in the manufacturing sector. The literature review is followed by a case study identifying barriers to CE as seen by ten companies within manufacturing, including the GS1 global information standardisation agency used by all manufacturers.

Findings – The manufacturers investigated focus mostly on recycling and waste reduction. These policies have low or very low CE effect. High CE effect policies like maintenance and reuse targeting the CE ideal of no waste, are nearly non-existent. The results identified seven main barriers to the CE: (1) high start-up costs, (2) complex supply chains, (3) challenging business-to-business (B2B) cooperation, (4) lack of information on product design and production, (5) lack of technical skills, (6) quality compromise and (7) disassembly of products is time-consuming and expensive.

Research limitations/implications – The data come from participants in a single country, Norway, although the manufacturers are multinational companies adhering to enterprise policies.

Practical implications – This research shows that all the companies interviewed are well aware of the growing need for their company to move towards more sustainable operations involving CE concepts. The barriers identified are explored, and the findings could guide such companies in their efforts to move to maintenance, reuse, remanufacture and recycle (M+3R) operational model.

Social implications – The study has found that the major barriers for implementation of CE are quality issues in recycled materials, supply chain complexities, coordination problems between companies, design and production of the product, disassembly of products and high start-up/ investment costs.

Originality/value – The research shows how the transition towards a CE takes place in manufacturing industries by studying the manufacturing sector.

Keywords Circular economy, Manufacturing industry, Barriers of circular economy

Paper type Case study

Introduction

Whilst globalisation gives both a larger market and increased competition, the companies' supply chains have become more complex and critical than before (Majta, 2012; Sheffi, 2018). The rate of worldwide consumption has increased eight times over several decades, and it is expected that the resource use globally will increase three times more until 2050 (Lucas, 2014). The effect of population growth and the subsequent increase in consumption challenges the environment, overall society and the depletion of scarce resources (Damen, 2012; Ellen MacArthur Foundation, 2014). The resource consumption of the linear model follows the take-make-consume-dispose pattern. This is not sustainable as the over-use of scarce resources contribute to pollution of the environment. Cities are generating 1.3 billion tonnes of waste each year, with significant overuse of trash landfills. This figure will surge to 2.2 billion tonnes by 2025 (Masi *et al.*, 2017). Electronic waste is another kind of waste that is increasing

Journal of Enterprise Information Management

1741-0398
DOI 10.1108/JEIM-02-2019-0047

quickly. We know that waste and trash have a negative impact, with our oceans accumulating plastics, endangering marine life, animals and wildlife affected by too many pollutants, persistent use of chemicals causing disease, depletion of the ozone layer and global warming, all leading to a focus on taking serious action against waste.

Businesses and their supply chains in their need to satisfy their customers must increase the price of the materials because of the increasing scarcity of resources, which again affects progress and profitability of the companies in a negative way. In considering demand, more pressure of environmental concern from customers is seen to result in more eco-friendly products. The CE model is based on the concept of changing the take-make-use-dispose pattern into closed loops of material flows. Closed loops of materials are possible through different functions i.e. maintenance, repair, reusing, refurbishing, remanufacturing and recycling. This creates the synergy effect between economic development and the environment (Masi *et al.*, 2017). Supply chains are considered to be an important factor for the implementation of the CE model because of the need for a joint effort by suppliers and manufacturers. The cooperation and coordination between supply chains "upstream" and "downstream" partners are essential, as upstream partners obtain eco-friendly inputs cooperating with downstream partners for environmental management practices such as product return, reuse and recycling (Zhu *et al.*, 2010). The transition to CE is not easy, as is evident from previous studies. Due to these barriers, firms are slow to make a transition towards the circular economy (CE) (Masi *et al.*, 2017; Preston, 2012). This research targets the barriers to the CE in manufacturing industries and the ways these barriers can be overcome.

The paper first defines manufacturing industries and considerations leading to a clear research question, then clarifies the CE concept in relation to the definition of manufacturing industries. A literature review follows, identifying barriers to CE found by other researchers; then the case study with sections on research methodology, data collection and the primary data from interviews with the ten companies. Lastly, the paper presents discussion and a summary of findings contributing to practice and theory.

Manufacturing industries

This study defines manufacturing industries as the industries that use highly equipped machines and digital instruments that are helpful in their production. Examples of these kinds of industries include the construction industry, automotive industry, defence and arms industry, energy industry (electrical and petroleum), computer industry and aerospace industry. These industries work with massive machinery, heavy metals, digital and complex mechanical instruments, drills and cranes and other heavy transport equipment and appliances (GS1, 2018). It is crucial for these industries to have a secure method to recycle or dispose of metal and electronic waste that can have hazardous effects on our environment. There have been challenges in recycling and disposing of these types of machinery and metals as they include elements and products that cannot be extracted easily.

The manufacturing sector is a cornerstone of the economy, crucial to sustainable economic growth, but the manufacturing industries are bound by tradition where change is slow and costly (Herman, 2016; Lieder and Rashid, 2016). Also, value creation is changing and customers expect value co-creation, connectivity and sustainable operations, blurring the distinction between manufacturing and services. The CE is more complex than the linear model, resulting in barriers to a move towards CE (Hopkinson *et al.*, 2018). Companies are faced with a range of technological and cultural barriers to overcome, and for manufacturing companies, it is imperative to understand what barriers they face to take appropriate action. This paper presents barriers to CE adoption identified by a literature review, and it addresses the particular challenges faced by manufacturers expressed by the research question: What are the dominant barriers faced by the manufacturing industry in moving towards a CE?

Circular economy

Adoption of CE concepts have been the focus of the food industry for several decades. Irani and Sharif (2018) explored the role of sustainable food security with closed-loop business models. CE can be seen as consisting of two parts: the first part focusing on reducing the impact on the environment, and the second part focusing on creating business models that implement the first part (Torstensson, 2016). For the first part, reducing the impact on the environment, the Ellen MacArthur Foundation (2015) has given a model of circularity that shows which activity cycles give the highest positive environmental impact. The cycles focus on a material's next use. The best next use would be to close a cycle instead of going to a cycle with lower CE effect or in to the waste chain.

Figure 1 illustrates the maintenance, reuse, remanufacture and recycle (M+3R) cycles and waste chain. Maintaining has the highest CE impact, followed by reuse, remanufacture and recycle. The waste chain has the lowest CE impact (Ellen MacArthur Foundation, 2015; Torstensson, 2016). The waste chain consists of waste collectors, energy-from-waste operators and landfill operators.

The ultimate CE goal is sometimes denoted as a "cradle-to-cradle" model, as described by Michael Braungart *et al.* (2007). This is a holistic model that seeks to create systems that are essentially waste-free. In principle, products and its constituent and parts are used in a regenerative manner without losing their quality, never reaching the waste chain (as seen in the lower part of Figure 1). This CE model is linked with the industrial ecology (IE) concept that challenges the current view that the industrial systems and the environment should be handled separately. The IE theory says that the industrial system is a kind of ecosystem where the materials are distributed, while energy and information-flow take place through the assistance of the biosphere. Hence, IE argues that the industry and environment cannot be separated from each other (Erkman, 1997; Liakos *et al.*, 2019).

According to Zhijun and Nailing (2007), shifting towards a CE model requires a deep focus on raw materials and energy. When producing a product, the focus should be on minimising the entire product life cycle's negative effects on the environment from the very early stage of material extraction towards the product disposal. Bocken *et al.* (2016) describe how to adapt product design and business model strategies to a CE. CE activities require new business models in which one pursues the opportunities for a shift from an "end-of-life" focus to a cradle-to-cradle cycle, from using un-renewable energy towards using renewable, from using toxic chemicals to their elimination, from waste to eliminating waste by design of materials,

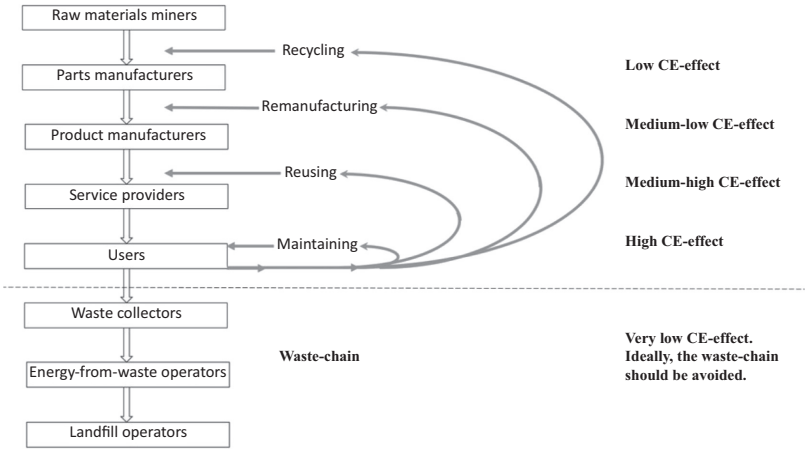

Figure 1. CE as a restorative system for technical products with the M+3R cycles in the upper part and the waste chain in the lower part (adapted from Ellen MacArthur Foundation, 2015)

products, systems and business models (Ellen MacArthur Foundation, 2013; Torstensson, 2016). This implies that ideally, there should be no waste, avoiding the waste chain completely. According to the Ellen MacArthur Foundation (2013), business models involving servicification are central to achieve this.

Barriers to CE

A shift to the CE model or any other business models for sustainability of the economy requires a dramatic change for the whole company, including all the stakeholders. This shift is somewhat disruptive in nature because the current mode of working would also be changed due to the new solution of the CE model (Ritzéna and Sandström, 2017). To obtain more in-depth answers to the research question, we link the barriers seen by manufacturers with barriers identified in the research literature. In this research, there are three parts:

(1) to identify the barriers to CE in the research literature;

(2) to identify barriers to CE experienced by manufacturers; and

(3) to classify the barriers identified by companies according to barriers found in literature.

The first part is to obtain more in-depth answers to the research question by linking findings by manufacturers with existing literature on barriers to CE. For this, an exploratory review of the existing literature has been undertaken. The academic databases such as Google Scholar, Scopus, ProQuest and ScienceDirect were used. Keywords such as "circular economy", "product identification", "sustainability" and "barriers to circular economy" were used. In the main, white papers, reports, governmental publications and scientific journals were used as secondary data. Table I summarises the barriers in implementing the CE model found by Preston (2012), Liu and Bai (2014), Eijk (2015), Torstensson (2016), Berchicci and Bodewes (2005).

Data collection

This study uses a qualitative approach method using data from semi-structured interviews. According to Yin (1994, p. 19), research design is the action plan to help a researcher execute the research from its inception to its conclusion. It does this by providing the researcher with "the initial set of questions to be answered, and there is some set of conclusions (answers) about these questions" (Yin, 1994). A case study approach was adopted as the primary research method for data collection. The case study approach as a research method for data collection is being widely used as a "common research strategy in psychology, sociology, political science, business, social work, and planning", as it has the potential to make unique contributions "to our knowledge of individual, organisational, social, and political phenomena" (Yin, 1994, p. 2). The unique characteristic of the case study approach is the ability to acquire and "retain the holistic and meaningful characteristics of real-life events" (Yin, 1994, p. 2), which can be of tremendous importance in any sociological research study. To fill the gap in research on a limited understanding of the barriers of a CE for manufacturing companies, a multiple exploratory case study approach was adopted as the primary research method for collecting data.

Our primary data are obtained through the use of semi-structured interviews from manufacturing companies. Qualitative semi-structured interviews are one of the most dominant and widely used methods of data collection within the social sciences (Bradford and Cullin, 2012). Interviewing specific companies who work with industrial manufacturing give knowledge on their approach towards sustainability and the CE concept. The ideas and views given by the companies were observed and analysed through an interpretive measure. Our

Barrier	Description	References
Resource-intensive development models	Traditional models are highly resource-intensive; less resource-intensive models are lacking	Preston (2012)
High start-up costs	In the long run, the CE model would show sustainable benefits and increased growth. But, in the short run, the start-up costs are high involving, e.g. retooling machines, relocating factories, building new distribution and logistics arrangements and retraining staff. Lack of budget towards the CE model innovation. Lack of industrial symbiosis is a barrier towards CE because it is costly. Quality assurance for recycled material to be handled in a good manner is costly	Preston (2012), Liu and Bai (2014), Eijk (2015), Torstensson (2016)
Complex supply chains	Because production and consumption often take place in different countries, supply chains may need to be reorganised to facilitate reuse and remanufacturing. Incentives throughout the supply chain are needed for companies to actively consider sustainable materials, durability and reparability. For the CE transition, the existing network should support switching between transportation modes	Preston (2012), Eijk (2015)
Challenging B2B cooperation	A barrier is coordination across companies because it needs multiple companies to adjust their daily operations. This potentially gives large transaction costs and delays in negotiating among companies. Industrial symbiosis requires information exchange to get knowledge of material and energy flows, which is costly or difficult	Preston (2012), Eijk (2015)
Innovation diffusion challenge	It is critical that new breakthroughs rapidly find their way into the mass market so that transition to the CE can contribute to tackling climate- and water-related goals in the necessary timeframe	Preston (2012)
Structural	Innovation and flexibility are restricted by organisations' hierarchical patterns. CE`s strategies are affected by the managers' employment term restrictions	Liu and Bai (2014)
Contextual	Competition in the market place restricts the movement towards CE	Liu and Bai (2014)
Cultural	Managers are risk-averse	Liu and Bai (2014)
Restricted supply chain	There is a lack of enablers to improve cross-cycle and cross-sector performance. Lack of exact knowledge of the composition and origin of materials used	Eijk (2015)
Lack of industrial symbiosis	Industrial symbiosis is based on having good knowledge of material and energy flows within an industrial sector and geographical area. It requires an exchange of information regarding inputs and output to optimise the processes, but this industrial symbiosis is a barrier towards CE because it is costly or difficult to obtain	Eijk (2015)
Logistics	Information exchange systems in logistics are limited. Cargo flows are handled by logistics, which also includes the reverse logistics and supply chain management. For the CE transition, existing network design is a barrier. The design should support switching between transportation modes	Eijk (2015)
Lack of information on product design and production	Removing of toxic material and separation of biological from the technical substance is lacking. Shortage of information regarding green suppliers. Current product design is given less attention towards the end phase of products	Eijk (2015)
Recovery	The products are becoming more complex; the recovery of such products is a big challenge	Eijk (2015)
Recycling	Recycled materials are sometimes more expensive than the new raw materials. Investing in recycling is seen to be risky on a larger scale	Eijk (2015)
Lack of technical skills	A barrier towards the implementation of CE is the lack of skills in small- and medium-sized enterprises. They do not realise the benefit of implementing more advanced technologies that reduce the negative impacts on the environment and would give them costs savings	Rizos *et al.* (2015)

(*continued*)

Table I.
Identified barriers in literature

Barrier	Description	References
Quality compromise	Companies' reluctant attitude towards CE is their concern regarding the quality of materials. They fear materials would be chosen based on the environmental aspects instead of the quality of performance	Torstensson (2016)
Disassembly of products is time-consuming and expensive	A product is made of many different components that are attached in a way that their disassembly is hard and time-consuming, and it seems much better to produce a new product than to recirculate the materials, and also it would be very expensive to mould the components in a way they could be available to use again	Torstensson (2016)
No surety CE will help the environment	Companies cannot be sure that recycling, remanufacturing and reusing will save money or protect scarce resources, and it might be the case that producing a new product is less costly than reusing the old one	Torstensson (2016)
Quality assurance	A barrier is that it is difficult to know what has exactly been done with the material and whether the recycled material is handled in a manner that is good with respect to quality, and all these things involve costs	Torstensson (2016)
Design irrespective of CE	The products that are produced lack a circular design, which is the reason the reusing, disassembly, remanufacturing, etc. is hard	Berchicci and Bodewes (2005)
Hygienic issues	Some perceive that recycled or reused materials are not safe and hygienic	Berchicci and Bodewes (2005)

Table I.

interpretation leading to the identification of barriers as seen by manufacturers are based on the subjective perceptions of the employees interviewed at each company. This gives an indication of what barriers they face. Specifically, we attributed statements in the interviews to barriers already identified in the research literature (summarised in Table I). For example, for Company 1, the authors asked the question regarding the circular economy. The respondent said that almost 95 per cent of the engine parts and equipment are recycled and have high quality, but the main barrier is the cost of recycling. From this, we find that Company 1 faces the barrier "high start-up costs". This classification is summarised in Table II for all companies. As we investigate a social phenomenon, our qualitative analysis of the interviews is based on our interpretive classification. It was not codified or statistically analysed. This approach satisfies our goal by this research in classifying the barriers to CE transition according to the companies' point of view with the barriers derived from the literature.

Interview execution

During the interviews, notes were taken to avoid the loss of important information. The interview guide was changed a little, based on the participant company, i.e. some questions were added for GS1 Company and the context of one interview guide needed to be amended for another. Five interviews took place face to face, four by phone and one via email.

How qualitative data analysis is done

For a detailed analysis of primary data, a general analytical procedure was conducted. For the purpose of qualitative analysis and getting a true picture of the interviews, they are transcribed. In transcription, special attention has been given to accuracy by focusing on the shortening of sentences and elimination of words that were repeated. Coding is used on transcripts to make the data accurate and precise. Coding is the method of reading the text carefully and considering all the meanings in the text and making categories (Thomas, 2006).

Barriers identified in the literature	Barriers identified by manufacturers 1	2	3	4	5	6	7	8	9	10
Resource-intensive development models										
High start-up costs	*v*		*v*	*v*	*v*					*v*
Complex supply chains			*v*		*v*					
Challenging B2B cooperation			*v*		*v*	*v*			*v*	
Innovation diffusion challenge										
Structural										
Contextual										
Cultural										
Restricted supply chain										
Lack of industrial symbiosis										
Logistics										
Lack of information on product design and production			*v*						*v*	
Recovery										
Recycling										
Lack of technical skills								*v*		
Quality compromise		*v*	*v*			*v*				
Disassembly of products is time-consuming and expensive	*v*	*v*	*v*							
No surety CE will help the environment										
Quality assurance										
Design irrespective of CE										
Hygienic issues										

Table II.
Barriers in literature and by companies

Companies interviewed: 10. Total number of persons: 14

To identify barriers to CE by manufacturers, we made a list of manufacturers in Norway from which we selected ten companies of various size, from small companies with a modest turnover and tens of employees to large multinational companies with billions in turnover and thousands of employees. This would get us a broad overview of companies of various sizes. The interviews were conducted by approaching persons who have deep knowledge of the operation of the company. We selected companies with head offices in Norway because this research is part of the Manufacturing Networks 4.0 research project funded by the Norwegian Research council. As all companies have extensive international operations with global reach, the information collected is considered to be representative of manufacturing companies in general.

Companies 1, 2, 3, 4, 5 and 6 were big, multinational companies all having a sustainability strategy in place communicated throughout the company via top management and dedicated corporate social responsibility (CSR) staff. The authors anticipated top-level managers to be well aligned with the stated company strategy on sustainability and CE. Thus, mid-level management were targeted for the interviews, as this would give an insight on how well the strategy is communicated in each company.

The smaller companies had no documented strategy for sustainability or CE, i.e. Companies 7, 8, 9 and 10. As in small companies the communication among employees is more direct and verbal, senior management representatives were selected for interviews.

Company 1 is a manufacturer of marine products like engines, power systems and digital elements for marine vessels with an annual turnover of €919m (2017). It is the marine subsidiary of a global manufacturer of power and propulsion systems for use on land, at sea and in the air. Their corporate environmental strategy promoted through their annual report from 2017 focuses on reducing the environmental impact, developing low emission products and reducing the impact of business operations. The person interviewed was a supply chain manager responsible for the flow of material in and out of the company. The company seeks

to minimise its effect on climate change through a low carbon strategy; a corporate goal to reduce environmental impact of production and a commitment to improve the environmental performance of its products. Furthermore, they are strongly committed to health, safety and environmental management. The respondent said:

> We don't exactly use the term circular economy, but we have all the focus on environmental protection. We have a programme called Revert which is about minimizing the demand for the new materials in which the metals are being recycled.

On the question regarding the CE, the respondent confirmed almost 95 per cent of the engine parts and equipment can be recycled, but the main barrier is the cost of recycling. Through the Revert programme, tonnes of carbon dioxide are saved compared to using new materials. In addition to the cost of recycling, another barrier the respondent mentioned was the disassembly of the products.

It is evident from their strategic goals and the interview that Company 1 has a focus on the mid- to lower-impact CE strategies of recycling (ref. Figure 1) from a general environmental perspective, and with no specific reference to CE. Thus, Company 1 has less focus on the high-impact aspect of CE such as engineering of new products with maintenance and reuse in mind. The barriers of cost and disassembly mentioned earlier reflect this.

Company 2 is a manufacturer of professional lighting solutions for the onshore and offshore global market with an annual turnover of €236m (2017). The persons interviewed were their chief technical officer and head office group IT manager. Their goal towards a sustainable environment is:

> The total products that come to the end, do not end but they are used again to make something new. The main objectives of the company are; reducing wastes, diminishing energy utilisation, expanding reuse of products, environmentally efficient transport solutions and prohibiting emissions.

By law, the company is required to follow local and global standards and environmental policies, which is reflected in one of the answers from the employee:

> Our company's products also satisfy the WEEE Directives (Waste Electrical and Electronic Equipment). It has ISO 14001 environmental certification and policy for Corporate Social Responsibility (CSR) to support a precautionary approach to environmental challenges.

The interviewees mentioned several barriers to implementing CE. These were: little attention towards the end phase of the product, difficulty in disassembly due to the need to separate biological substances from technical products, difficulty in reusing the products, recycled materials being more expensive than new materials, recycling taking more time than using new materials, the potential reduced quality of recycled materials and mixing recycled and new materials increasing supply chain complexities. Of these, the main barriers identified were the quality issue and disassembly of products. Including used parts in a product might result in reduced quality of the final product because the reused parts may not be equally good as virgin parts. In addition, it might be hard to disassemble products and verify whether the recycled parts meet new standards.

National and international directives for electronic equipment implemented over the past few decades have dominated Company 2's efforts towards environmental aspects. The directives target the linear model handling the end phase of a product as waste, possibly after being recycled or "down-cycled" into products with less CE impact before ultimately becoming waste (Figure 1). In this regard the company has not yet achieved all it can with regard to circular economy. It could consider early stages of product design and material selection to better support a cradle-to-cradle model.

Company 3 is the global standardisation organisation GS1 (Global Standards 1). This company preferred not to be anonymous because promoting standards that help companies

move towards sustainable operations is a part of their strategy (GS1, 2018). GS1 is the leading global standardisation organisation in business-to-business (B2B) trade best known for the barcode and radio frequency identification (RFID) standards. GS1 has an office in most countries worldwide. In Norway, more than 6,300 companies are registered at GS1, giving GS1 a good overview of standards used by manufacturers. GS1 Norway has 15 employees. We interviewed Terje Menkerud, a senior advisor at GS1 in the Department of Delivery Standards. The respondent stated that the company is deeply committed to sustainability:

> We don't focus on circular economy per se but everything we do is based on sustainability and environmentally friendly ways of doing things and GS1 has focused on carbon footprints. .... Everything we have done has the circular economy approach applied. Everything we do is based on sustainability, efficiency and an environmentally friendly way of doing things not just in transport and logistics, but in everything we do from the healthcare sector, retail, and apparel sector to logistics sector.

He further explained that many players in the market have their own proprietary systems for identification of products, leading to B2B cooperation being a big challenge, especially when combined with the complexity of supply chains. GS1 standards can help companies in extracting the harmful substances by giving companies a specific identifier to each of their products and each component. The lack of product information about product design and production is a barrier because the company needs accurate information for cost-efficient recycling, reusing, repairing and cost-efficient disassembly of products. He stated:

> A product attribute in the standards supports recycling to be registering what the product consists of, and how these products can be treated in a special way and how to recycle them. Labels related to environmental sustainability are put on the products.

It is evident that digitalisation and information management of individual products is required for manufacturers to move towards a CE model in a cost-efficient manner. Barriers of supply chain complexities, B2B cooperation, lack of information in product design and production, fear of compromising performance quality if environmental aspects are included and prohibitive costs for disassembly can all be mitigated by proper information management founded on global standards.

Company 4 is a world-leading manufacturer of aluminium with an annual turnover of €3.9bn. We conducted two different interviews, one at the corporate head office and one at a production plant. The respondent at the head office, a SAP consultant working on implementing the procure-to-pay process, had very good knowledge of the concepts of sustainability and CE. He stated (translated from Norwegian):

> We are focused on sustainability towards our customers, and also for our internal processes. As an example, we focus on the recirculation of used aluminium because recirculation requires only 5 per cent of the energy compared with producing new aluminium. We invest heavily in green technologies in Norway using renewable hydropower and advanced technology with lower energy consumption and low emissions.

Regarding the barriers to CE adaption, the respondent said "*The cost element is always a challenge. We need to balance the trade-off between investment and earnings*".

The other respondent at the production plant as a senior accounting consultant had less in-depth knowledge of sustainability and CE. He stated:

> Even if we do not use these terms on a daily basis, we focus a lot on the reuse of metal related to production. When the products are cut according to the preferences of customers, there will be left-over pieces and metal shavings.

Regarding barriers to CE adaption, the respondent said: "*I am not sure, most of the focus is on energy-efficient production, and some smaller initiatives on the separation of general waste for recycling*".

At GS, there is a clear understanding of the importance of CE at the head office showing that overall corporate CE strategy is well communicated at the central management level while being less more focused on specific operational issues related to implementing CE aspects at the plant level.

Company 5 is a manufacturer of furniture with an annual turnover of €220m. One interview was conducted with two persons at the corporate head office. One was CSR manager and one was e-commerce coordinator. Both had very good knowledge of the concepts of sustainability and CE. The e-commerce coordinator stated (translated from Norwegian):

> We have conducted projects on sustainability in logistics, in marketing and in business operations where we have studied various circular economy models. Regarding barriers, we move in this direction, but traditional supply chain structures hinder, e.g. direct distribution avoiding intermediaries. Another aspect is the cost of making second-hand-friendly products versus getting payback for doing it.

CE adaption at Company 5 focuses on the business model, how to be paid for the cost of turning the value chain towards re-useable furniture. The lock-in at the linear manufacturer – retailer – customer business model is a barrier. They explained that the role of retailers is diminishing, while e-commerce to end-customers are increasing in the market. The B2B cooperation is challenging. Existing retailer contracts hinder a smooth transition from the old to the new model, and it is too risky to make a disruptive move leaving out the retailers. The costs might be too high in changing to e-commerce trade channels.

The respondents further stated regarding barriers "*The new regulations on public spending from 2017 requiring buyers in the public sector to weight the environmental aspect in the tendering process as well as a major criterion in the decision process has had a big effect. It has spread to the oil and gas business and the hotel chains*".

Company 5 has an increasingly complex value chain with more trade channels, more environmental-related regulations and higher awareness among customers on CE issues. This company is still in its infancy in its transition to a CE model. Furniture has no established specific recycling value chain like for electrical products; thus, at the end phase of a product, it is treated as household waste entering the CE waste chain in Figure 1. They are aware of the market demand for a restorative system, but the main barriers of costs and supply chain complexities are hard to overcome.

Company 6 is a manufacturer of marine propulsion and thruster systems with an annual turnover of €100m. We had one interview with two respondents: The executive vice president of health, safety, environment, quality and sustainability (HSEQ) and the manager for product development. Both had very good knowledge of the concepts of sustainability and CE. The company strategy is according to what they called "The green maritime shift" leading to sustainability and CE being important strategic focus areas.

Related to barriers, they said there is a risk of lower quality of some recirculated components compared to new components. For example, metal parts experience structural damage when subjected to strains. There is a lack of traceability in the value chain after delivery, and Company 6 said the marked for service models like "power by the hour" are immature. Their production follows an engineer-to-order strategy with frequent changes in product design during production resulting in challenging B2B cooperation towards suppliers. Their customers are shipyards with a strong focus on short delivery time, with less concern of environmental aspects like energy consumption when during the ship's operations. Thus, different B2B actors are not well aligned.

Company 6 has strategies towards the green maritime shift, looking at using recycled components. Recycling has low CE impact (Figure 1). They look at new business models like

power-by-the-hour selling power instead of ship engines, which would enable optimised maintenance schemes with high CE effect (Figure 1). However, Company 6 finds that the market is not ready for such solutions yet.

Company 7 is a manufacturer of automated fish handling systems with an annual turnover of €115m. The person interviewed was a senior engineer working on product design. They develop, produce and install systems for use on ships and on aquaculture installations. The company headquarter is on the west coast of Norway with subsidiaries in Spain, Romania and the USA. The respondent stated (translated from Norwegian) "*I have not used the concept of CE, but we have a strong focus on environmental aspects. The machinery we produce, combined with German industrial machines minimises scrap*".

The interview and Web-based business communications indicate that Company 7 focuses on traditional environmental issues like reducing waste. In the ideal CE model, waste should be omitted, omitting the waste chain in Figure 1. Based on this, Company 7 operates in a traditional manner with no stated strategy of moving towards a CE model.

Company 8 is a manufacturer of marine generator sets for maritime applications with an annual turnover of €22m. They follow an engineer-to-order manufacturing strategy, producing tailor-made solutions. Their main business is deliveries of diesel engines, propulsion systems and generator sets for diesel-electric maritime systems. In addition, Company 8 provides services for applications on express boats, ferries and for the oil and gas industry. The interview was with the director of business development and the manager of power and propulsion systems. They stated that they focus on eco-friendly and low-emission solutions using permanent-magnet technology changing from diesel engines to electrical engines. Permanent-magnet motors can meet the strictest environmental requirements set for express boats and ferries. The respondents said the company focuses on adaption to a CE for service operations and for return logistics. Of challenges (barriers) they mentioned: lack of a system for reuse of batteries, lack of competence for putting CE into practice and that new service-based models are challenged by existing models.

Redesigning products to use electrical engines instead of diesel engines will have a high CE effect, as it enables other operational regimes for maintenance, reuse, etc. with high CE effect. This is a small project-based company with close communication between management and operational staff, enabling them to adapt fast to new market drivers.

Company 9 is a manufacturer of thermoplastic products with an annual turnover of €8m. The interview was conducted with the managing director. He had good knowledge of the concepts of sustainability and CE. The respondent stated (translated from Norwegian) that they focus on recirculated products for farmed fish enclosures such as fish ponds. Challenges mentioned (barriers) were how to change to manufacturing products based on recirculated materials. New service-oriented business models aligned with the CE concept will cause challenges regarding B2B cooperation requiring new contracts and partnerships.

Company 9 concentrates on increasing its use of recycled materials, especially expanded polystyrene (EPS), an approach with low CE effect (Figure 1). If the discussed service models are realised, they have the potential to move the company towards operations with a higher CE effect.

Company 10 is a manufacturer of industrial automation systems with an annual turnover of €3.5m. The managing director was interviewed. He had some knowledge of the concepts of sustainability and CE, saying, "*I have partial knowledge of these terms. It depends on what you mean*". After clarifying this was related to the goal of environmentally friendly manufacturing, he stated "*We have looked at it for BIM (Building Information Management) systems, e.g. when demolishing buildings and the need for information handling promoting reuse of components. We have also discussed using blockchains to register transported cement and gravel on ships*". Regarding barriers, the respondent said: "*It is a cost issue; potential*

solutions will not get used unless there is a clear way to get profit from it. A favourable cost-benefit analysis is hard to find".

Company 10 has no strategy related to CE. They are partly familiar with the reuse of building components, an industry with a growing use of automated documentation services. If realised, the reuse of materials has a medium to high CE effect (Figure 1).

Analysis

This section focuses on the data collected in the semi-structured interviews of the ten companies. Most of the respondents involved in the research do not use the words "circular economy", but their efforts towards environmental protection and sustainability have a base in this concept. Most of the manufacturers (Companies 1, 2, 3, 4, 5, 6 and 9) have identified activities involving recycling of products or using recycled materials as part of their production. This show they are focused on low CE effect operations according to the CE model in Figure 1. None of the manufacturing companies has active business models funded on regenerative operations with high CE effect. Thus, they lack an explicit focus on the cradle-to-cradle cycle with the ideal goal of eliminating waste by design of materials, products, systems and business models.

The barriers identified reflect this. For example, regarding the barrier "high start-up costs", the respondent in Company 2 mentioned, "recycling is more expensive than the virgin materials". Here, the respondent focused on recycling and the cost barrier. Company 2 overtly recognises its goal towards a sustainable environment and the necessity of charging their customers a small recycling fee that is transferred to the recycling funds to handle recycling. Company 2 has membership in an association of recycling companies that make sure electronic product waste is handled carefully, and that products are reused instead of new raw materials. By doing this, energy consumption is saved, and environmentally friendly products are produced by reducing the global waste. The company is also certified with ISO 14001:2004. This enables the company to comply with the rules and regulations of the environmental management system, thereby reducing the negative effects on the environment.

In the same manner, regarding the barrier of "complex supply chains", all respondents said that the disassembly of products is not easy. The large manufacturing companies (Companies 1–6) have written strategies that give special attention to regeneration of resources, and they have special programmes to implement such concepts as illustrated by the "Revert project", the "sunshine program", etc. These regenerative actions, e.g. aluminium and EPS, are a form of recycling requiring with high demand for energy. Thus, they focus on recycling, and not reuse or maintenance. Similar reasoning was found for the remaining barriers identified, i.e. "challenging B2B cooperation", "lack of information in product design and production", "lack of technical skills, quality compromise" and "disassembly of products is time consuming and expensive".

The barriers identified in the literature review section (Table I) varies, some are general barriers and some are related to the supply chain. The barriers identified by the companies we have interviewed mostly focus on the supply chain and product-related barriers in particular. The next section summarise the barriers authors identified based the interviews with manufacturers.

Barriers identified to the CE in manufacturing industries

Based on the results in the "all data collection" and the "analysis" sections classify the barriers to fit with barriers identified in the literature. This classification is summarised in Table II for all companies.

When explaining the CE barriers, the first barrier that is mentioned by the respondents is the high start-up cost. This fact is also supported by the literature (Preston, 2012) Liu and Bai (2014). Every business needs to consider the cost of transition towards any new model.

The next barrier that the two respondents have mentioned is the quality issue of recycled materials, as identified by Torstensson (2016). Another barrier identified is that recycling requires a technology-intensive process that needs such high-level testing protocols to ensure that the recycled materials are according to the specification of the customer, that it is difficult to attain. This is supported by Holmes (2018).

One respondent believes that coordination problems between companies can be a barrier, but it depends mainly on the company and the way they think about the environment and the scarce world resources. In the literature, this phenomenon is considered as a barrier too (Preston, 2012). This also requires international coordination among companies because the transition from linear to CE requires a change across borders (SMO Promovendi, 2017/2018).

In end-of-life (EOL) management, the disassembly of products is considered to be an important element. It is considered that almost every product has some amount of disassembly, i.e. irreversible joints, maintenance and upgradation and degradation during use. It is not actually the reverse process of assembly. If the instructions of disassembling are available with other relevant information such as design and lifecycle information, this will ultimately help in product disassembly automation and decrease disposal of components (Preston, 2012). All the respondents said that the disassembly of products is not easy and is expensive and time-consuming because of the complexity of products, and this fact is also supported by the literature (Torstensson, 2016). The complexity comes due to different aspects. The number of materials has increased, and many small materials are used with significant importance as well as the multiple components of a different nature. These all come together to affect the transition towards a CE. If the resources contained in these materials and components are taken back through repair, upgrade or remanufacture this can be of benefit the world over (Preston, 2012).

Another barrier that the companies have mentioned is that the technology sector pays less attention to the end phase of a product (Eijk, 2015). One of the problems is the production of cheaper goods, shorter life expectancy and low-cost and unsustainable products in today's corporate culture. The culture of companies is, when they make a product, they do not feel the need to consider how the product will end its life. Once the manufacturers produce the product and send it off for sale, they are not usually responsible for the end phase of the product's life. Furthermore, there is a lack of information available when recycling or reusing any product in the end phase of life. Product information is necessary to identify and know about the product parts for appropriate disposal. This has encouraged governments and organisations to make strategies to pressurise companies, and the corporate world to be more responsible while producing and to have strict environmental considerations and policies (Hesselbach *et al.*, 2001).

From the interviews, it is evident that manufacturers investigated mainly focus on the lower impact CE strategies and the waste chain (Figure 1) and less on the elevated strategies with a deeper impact on company operations, leading to regenerative approach from the design on new products through the lifecycle management of products and in their manufacturing business.

Discussion

The manufacturing companies investigated all are aware of the growing importance of the environmental aspects mentioning efforts to increase reuse, lower CO_2 emissions and reduce waste. Authors' investigation shows that the transition from traditional environmental considerations towards circular models faces several barriers.

Global corporate strategies implemented at the large multinational manufacturers are communicated to subsidiaries. For example, Company 1 promotes a commitment to reduce the environmental impact in their business communications. An example is an annual report; "*This commitment is embedded within our governance framework, including our operating*

system and production system, and therefore is not a standalone environmental policy". The smallest manufacturing company, Company 10, does not have a company strategy on sustainability or CE. This indicates that the company size matters for how fast companies move towards CE, but for different reasons for large and small manufacturers. Large manufacturing companies have the knowledge to make a strategy for moving towards CE, but are slow move as it takes time to propagate the strategy to its subsidiaries. Smaller manufacturers lack a unified documented corporate strategy for moving towards CE, but they are able to move faster. An example is Company 6 that has developed the "power by the hour" service model, but the market is not ready for it yet.

Attributed to the quality compromise barrier that concerns the reluctance of putting weight on environmental issues because they fear it will compromise other qualities like performance and the quality of the end -product. As the barriers are based on multi-faced and the multi-dimensional barriers point to significant issues that need to be addressed, rather than a narrow topic. Clearly, quality compromises and assurance barriers are related. To highlight the CE aspects, we have categorised the responses into barrier classes based on the characteristics of the CE mode described in the $M+3R$ model in Figure 1, i.e. according to the level of CE impact by maintenance, reuse, remanufacturing and recycling plus waste.

Conclusion

In this research, the authors have explored how the transition towards a CE takes place in manufacturing industries by studying ten companies. For the research question*: what are the barriers to the circular economy in the manufacturing industries supply chain?* The authors have found that the major barriers for implementation of CE are: quality issues in recycled materials, supply chain complexities, coordination problems between companies, design and production of the product, disassembly of products and high start-up/ investment costs.

This shows that the companies are well aware of the challenges of moving towards the CE. The research further shows that the companies currently have a traditional CE focus attending to policies placing their efforts as low CE effect or very low CE effect actions. In practice, this means they focus on recycling and reducing waste. They have little or no focus on the ideal no waste scenario and to a very little extent on high CE effect. Activities related to servicification can be seen as having high CE effects, as servicification is an important part of the no waste ideal. However, the servicification attempts seems to come more from a need to address market trends than a strategic move towards high CE effect activities. This research classified the barriers to CE transition according to the companies' point of view with the barriers derived from the literatures. This classification would be beneficial for the concerned companies, for two reasons. The first one is that it would provide an understanding of the different company's views about the barriers. The second reason is that this enable them to focus on overcoming the barriers that are found to be important to operations with high CE effect.

Limitations

The CE concept is emerging, and manufacturers know this concept, but the actual shift towards a circular model is slow in its progression. Companies in this research have promoted their CE commitments and barriers in implementation they experience; in reality, have not adopted the CE concept in full. The data come from the participants in a single country, Norway, although the manufacturers are multinational companies adhering to enterprise policies.

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