

Industrial Symbiosis in the Cement Industry - Exploring the Linkages to Circular Economy

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Abstract Policy makers, industries and academia acknowledge industrial symbiosis (IS) as a strategy for facilitating circular economy (CE) since it evolves around the notion of closed-loop resource circulation. Through IS companies exchange materials, energy, water and by-products, thus promoting cleaner production, improved resource efficiency and lower CO₂ emissions. There exist ample studies analyzing the benefits of IS partnerships for companies. Nevertheless, demonstrative cases on how the link between IS and CE occurs in practice seem to be limited. This study aims at filling that void by examining twelve IS partnerships at a large cement producer in Denmark and linking them to Ellen MacArthur's "Circular economy systems diagram". The study furthermore adds to the discussion of the impacts of CE on businesses, by exploring the influence that the established IS partnerships have on improving resource efficiency.

Keywords: • circular economy • industrial symbiosis • By-products
• alternative materials • alternative fuels • case study •

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1 Introduction

Businesses and policy makers increasingly address the necessity to combat finite resource overuse that negatively impacts the environment (Bocken *et al.*, 2016) and instead to focus on strategies that promote sustainable development and cleaner production (Lieder and Rashid, 2016). At the same time, the engagement of industries is considered critical for sustainable growth (Yang and Feng, 2008). Circular economy (CE) is acknowledged as a key strategy for moving forward in that direction (Korhonen, Honkasalo and Seppälä, 2018a) as it seeks to decouple economic growth from development (Ellen MacArthur Foundation, 2017). CE is an industrial system, which focuses on keeping the embedded value in resources for as long as possible. CE aims at eliminating waste by implementing solutions for prolonging product life, reuse, remanufacturing, recycling.

One way companies have translated open-loop resource circulation in their business activities is through establishing industrial symbiosis (IS) partnerships. IS partnerships enable otherwise diverse industries to set up collaborative activities for exchanging wastes, by-products, energy, water, information, etc. (Chertow, 2004). IS sees the economic system as an integrated ecosystem where residuals from one industry can serve as a resource for another (Wen and Meng, 2015), lowering the initial demand for virgin resources. In the cement industry, for example, currently responsible for about 5 to 7 % of the global CO₂ emissions (Benhelal *et al.*, 2013), IS partnerships enable companies to get access to solid wastes as alternative raw materials and fuels, which results in a reduction of global CO₂ impact (Hashimoto *et al.*, 2010). According to (Saavedra *et al.*, 2018), a transition towards a more CE will not be possible without the presence of IS since IS partnerships establish the link between independent businesses for the exchange of by-products, energy, water, and even know-how (Saavedra *et al.*, 2018).

Despite the identified relation between the two concepts of CE and IS, the majority of the existing publications are in the form of literature reviews and conceptual studies (Wen and Meng, 2015; Lieder and Rashid, 2016; Sauv e, Bernard and Sloan, 2016; Mulrow *et al.*, 2017; Homrich *et al.*, 2018). Few studies explore the CE performance of IS schemes (Wen and Meng, 2015), but to our knowledge, little research appears to demonstrate how the link between IS and CE occurs in practice. Additionally, based on the extensive literature review of

Lieder and Rashid (2016) we can deduct that at large, present CE studies focus on how limited resources and the environment are impacted. Apart from a few examples (Lieder *et al.*, no date; Yu, Han and Cui, 2015), studies are not too specific on underlying what the benefits of CE for individual businesses are. That trend does not seem to correspond to the mindset CE theory supports, i.e. for having a focus on the whole product value chain, implementing new business models for takeback and design for easy disassembly, etc. Such business activities must have as much an economic drive as they are motivated by resource efficiency benefits (Korhonen, Honkasalo and Seppälä, 2018b). Our study elaborates on the link between CE and IS, through a demonstrative case study on a large cement producer in Denmark. Data was collected by semi-structured face-to-face interviews and the identified IS partnerships were linked to Ellen MacArthur's "Circular economy system diagram". Furthermore, in this paper we aim at filling the existing gap of the impacts of CE on businesses, by exploring how our company case benefits from the established IS partnerships.

This paper is structured as follows. Section 2 sets the stage with a brief introduction of IS, CE and the link between the two concepts. This section also includes a description of Ellen MacArthur's "Circular economy system diagram", also used as a framework for this study. Section 3 gives an introduction to the company case and the methods of data collection and analysis. Section 4 presents the results of the study and includes a discussion of our findings. Conclusions and limitations of this study are presented in the fifth section.

2 Background

2.1 Industrial Symbiosis (IS)

IS is a relatively new research field which emerges from the sphere of industrial ecology – a concept concerned with the flow of resources and aims at achieving economic, environmental and social benefits (Mirata, 2004). Industrial ecology operates on the levels of firm, inter-firm and regional/global (Chertow, 2000), while IS focuses on the resource flows from an inter-firm perspective (Chertow and Ehrenfeld, 2012). Resource flows include materials, by-products, energy, water, and information (Chertow, 2004).

In this study we use a broader definition of IS by (Jensen *et al.*, 2011) stating that IS are business relations (or synergies) with otherwise unrelated companies for the purpose of exchange and reuse of excess resources, i.e. raw materials, energy, water, steam, etc. Yet, in the results and discussion section of this paper we point at the benefits that geographical proximity offers in the case of sourcing alternative raw materials and fuels for the cement industry.

Academics appear to agree that IS is a tool that can help businesses reduce their dependency on virgin resources (Bocken *et al.*, 2016) and thus act as an enabler for CE (Nakajima, 2000; Wen and Meng, 2015; Sauvé, Bernard and Sloan, 2016). It is considered that companies enter into IS partnerships primary driven by economic motivations, i.e. reduction of raw material costs, lower waste disposal taxes, etc. (Desrochers, 2001; Lehtoranta *et al.*, 2011). Yet, positive environmental impacts have proven to go hand in hand with those partnerships (Ashton and Bain, 2012). In the cement industry for example, IS practices have brought vast reductions of greenhouse gas emissions due to the utilization of various wastes as alternative fuels and raw materials. In the Xinfeng Cement Industrial Park in China, for example, utilizing local municipal solid wastes for the cement production is proven to have the potential of generating reduction of about 3,000 kt CO₂/year combined with energy consumption savings, and bringing also economic and social benefits (Cao *et al.*, 2017).

2.2 Circular Economy (CE)

CE is a relatively new term, but the idea of an economic system, based on renewable energy where materials are circulating in loops and where waste is minimized or eliminated (Yuan, Jun and Moriguich, 2006), has been gaining importance for businesses, politicians and academics ever since 1970s (Geissdoerfer *et al.*, 2017). Compared to the traditional linear (extract-use-dispose) economy, which does not take into account the impacts on finite resource overuse or social capital, CE has a specific focus on minimizing resource overconsumption and identifying approaches for waste reduction and waste avoidance (Govindan and Hasanagic, 2018) by keeping products, materials and components at their highest value.

As it was the case with IS, CE also finds its origins in the fields of industrial ecology. CE considers the industrial system as an ecosystem where elements

interact and have the ability to reproduce (Korhonen, Honkasalo and Seppälä, 2018a). CE is inspired by biological ecosystems, where resources circulate in loops (Blomsma and Brennan, 2017). In the CE, the lifetime of components and products is either extended through repair, refurbishment and remanufacturing, or end-of-life products are recycled (Bocken *et al.*, 2017; Overgaard, Mosgaard and Rüssgaard, 2018). The closer the loops are to direct reuse, the lower the environmental externalities and the larger the social and economic savings (Wieser and Tröger, 2018).

CE is gaining importance for policy-makers on national, regional and international level. In 2015, for example, the European Commission issued a Circular Economy Action Plan, which has the ambition to move EU towards a more sustainable economy (European Commission, 2015). In Denmark, the government has identified the importance of the CE agenda for both the state and the business, thus implementing strategies for increasing resource efficiency and supporting companies in sustainable innovation (Ministry of Environment and Food in Denmark, 2018). China also translated CE into national law, i.e. “Circular Economy promotion law of the People’s Republic of China” (Lieder and Rashid, 2016).

There exist numerous literature studies on CE and related circular business models in the form of literature review studies, some examples are (Lieder and Rashid, 2016; Blomsma and Brennan, 2017; Geissdoerfer *et al.*, 2017; Homrich *et al.*, 2018). Central in the field is the Ellen MacArthur Foundation, a CE think tank promoting CE across businesses, governments and academia (Ellen MacArthur Foundation, 2017). Ellen MacArthur Foundation has various publications on the topic of CE, involving diverse company cases and recommendations to policy-makers on how make the transition from the current linear economic model to a regenerative one (Webster, 2015).

2.3 CE visualization

Ellen MacArthur’s “Circular economy system diagram” is a conceptual model, illustrating an ideal vision on how companies can minimize their waste by taking advantage of the reusability of products and materials (Govindan and Hasanagic, 2018). Figure 1 shows a remodified “Circular economy system diagram”. The emphasis is only on the technical materials and excludes the biological ones since

the focus of this study is only on the life cycle of technical materials, more particularly on cement. Each loop in the figure presents a different strategy for enabling the circulation of products and materials in the economic system. “Maintaining” is a strategy for keeping a product for as long as possible and prolonging its life through repair. “Reusing” refers to reselling or redistributing the product to different markers. “Maintaining” and “reusing” products are considered the most effective cycles, as the value of the product is preserved. If a product cannot be reused, most of its value can be conserved through “remanufacturing” it, i.e. replacing, rebuilding the no-longer usable parts of a product and thus giving the end product a new life. When the product cannot be reused, refurbished or remanufactured, the materials a product consists of can be “recycled”. In that way the value of the product might be lost, but the value of the materials can be conserved.

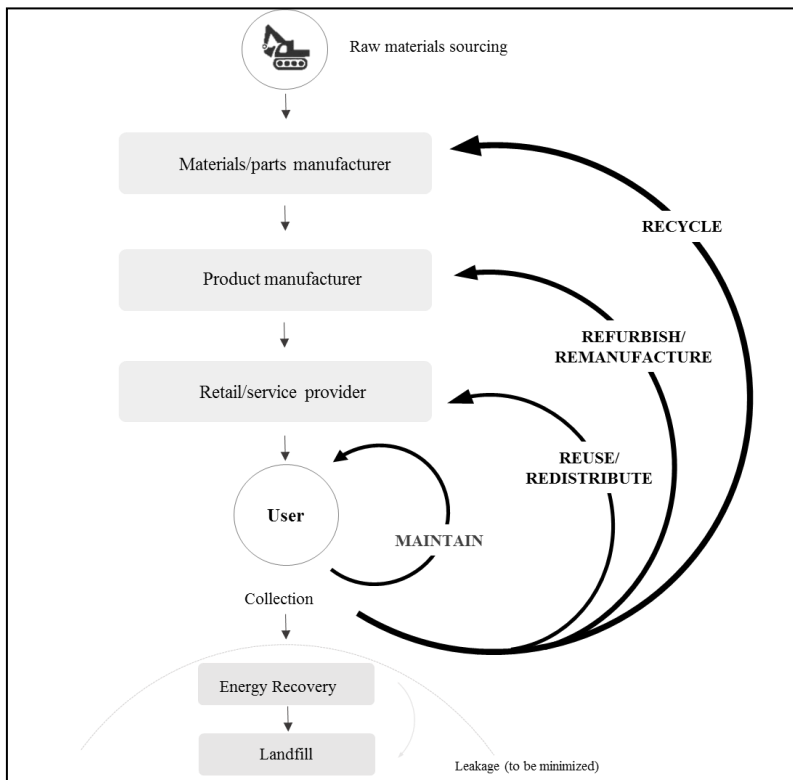


Figure 1: A remodified “Circular economy system diagram” (Ellen MacArthur Foundation, 2017) – edited.

3 Methods

This research aims at elaborating how IS links to CE. Due to the exploratory nature of the topic, a case study approach is selected (Eisenhardt, 1989) and twelve IS partnerships at a large cement producer were explored. Case studies provide us with the possibility to combine evidence from the 'real world' context in order to gain a general overview of company processes (Yin, 2013).

3.1 Case introduction

We carried out an in-depth case study of Aalborg Portland, a Danish cement company situated in Aalborg, Nord Jutland. Aalborg Portland is the world's largest producer of white cement. The cement industry was selected for this study for the following reasons. Firstly, sourcing the raw materials and fuels for the production of cement requires extraction of virgin resources and leads to air emissions (e.g. CO₂, SO_x, NO_x). Aalborg Portland it is considered a crucial source of IS examples, i.e. fossil fuels substitutes with industry wastes and by-products (Tsiliyannis, 2017), which are now recognized as opportunities for lowering those GHG emissions. In respond to the increasing focus on resource efficiency and emission control from the European Commission, our case company has publically communicated its deliberate strategy of using IS as a means of lowering environmental impacts from the production of cement and is continuously monitoring its environmental performance. Secondly, the company has recognized the importance of establishing synergies with both public and private organizations, as a mean for lowering resource input costs and improving resource efficiency (Mirata and Emtairah, 2005). Thirdly, the company is situated strategically with direct link to Aalborg harbour, making it an ideal case for establishing IS with both close and distant partners. Lastly, the company is situated close to the center of Aalborg, a city with an ambitious sustainability strategy and goals for implementing CE as a way to keep resources within the local borders. That gives the company an additional incentive to look for local partners when possible, improve its performance and be a key contributor for achieving the ambitious city vision for sustainable development.

Stages of cement production

In order to get a more clear understanding of the underlying potentials for improving cement via IS partnerships we briefly present the stages of its production. Figure 2 is a simplified illustration of the production stages at Aalborg Portland, and can be linked to cement production in general. The limestone extracted from a closely located quarry, while the rest of the raw materials are sourced externally. In our case company the limestone is partly located under the ground water table and is therefore wet when extracted, making the cement production a semi-dry process. At the next step, the raw materials are grounded and processed. The kiln process, being rather energy-intensive, requires heating the raw materials to 1500°C in order to form cement clinker, which is then further grounded and mixed with gypsum or mineral additives such as limestone, to produce cement. The cement is then packaged and transported. (‘CEMBUREAU’, 2017)

Even though we acknowledge that cement is not an end product, but an ingredient in the production of concrete, which in turn becomes part of a long-lasting construction, the boundaries of this study are within the cement industry.



Figure 2: A simplified illustration of the stages of cement production

3.2 Data collection and analysis

This study is inductive by nature, and involves the collection and analysis of both qualitative and quantitative data, giving us the chance to get detailed understanding of the IS partnerships at our case company (Maxwell, 2005). To avoid biases, data on the IS partnerships were collected by triangulation (Yin, 2011), i.e. three individual semi-structured face-to-face interviews with employees were conducted, written communication was analysed and data was verified by external experts.

The order of conducting the interviews and the main topics under discussion with the selected interviewees is described in Table 1. The interviewees were selected based on their professional experience and in-depth technical knowledge

on cement properties and impacts of changing the raw material and fuel mix of cement. The interviews were recorded or detailed notes were taken in the dialogue process. To increase the validity of the responds, the information collected during the interviews was subsequently confirmed by the interviewees and additional clarifying questions were raised.

Table 1: Interviews overview.

No.	Employee title at cement company	Area of expertise	Main topic(s) of the interview	Interview duration	Communication period
1	Quality and technical sales support	LCA analysis of cement production	<ul style="list-style-type: none"> Ongoing IS partnerships at the cement company – exchanged materials and their industry of origin Motivation and benefits of IS partnerships for the cement company 	½ hour	May-June 2018
2	Research specialist	New materials development	<ul style="list-style-type: none"> The utilization of alternative raw materials in the production of new cement types at the cement company Motivations and benefits of sourcing more alternative materials for the cement company 	1 ½ hour	June 2018
3	Concrete technologist	Concrete recycling	<ul style="list-style-type: none"> The possibilities of recycling and reusing concrete Motivations and benefits of recycling for the cement company 	½ hour	June 2018

Based on the interviews, additional internal company data was collected and analysed. That gave us a more complete overview of the effects of including alternative raw materials and fuels in the cement production process. Such internal data involved environmental reports, input-output analysis, chemical test results, material R&D projects, etc. To further increase the details and legitimacy of our findings (Yin, 2013), over the course of 2018, we verified the local role of the IS partnerships established by the cement company through informal communication with local municipal planners, environmental authorities and the local heat utility company.

We analysed the collected data through the following steps. Firstly, we identified which product life cycle stage of the IS partnering company the exchanged resource derive from and which life cycle stage of cement it influences. Secondly, we looked into what virgin resource is substituted/complemented through each of the IS partnerships. Thirdly, we grouped the exchanged resources according to their application at our company case, i.e. alternative raw materials, alternative fuels, energy, water. Fourthly, we identified whether the resource exchanged occurs on a local, national and international level, depending on the geographical proximity of the IS partner. Lastly, based on the preceding steps, each IS partnership was then linked to the loop of Ellen MacArthur's "Circular economy system diagram".

4 Results and Discussion

Section 4.1 will present the identified IS partnerships, where the exchanged resources derive from and what they act as a substitute for. Section 4.2 places the IS partnerships according to the loops of Ellen MacArthur’s “Circular economy system diagram” they influence. Section 4.3 provides a discussion on how IS partnerships can improve resource efficiency and as a result bring benefits for the company.

4.1 IS partnerships at case company

Based on the conducted interviews and additional data analysis, we identified twelve IS partnerships between the cement company and diverse industries. Three of those supply alternative fuels to the cement producer. Seven of the IS partnerships provide alternative raw materials. The last two focus on energy and water IS exchanges. The cement company sends excess heat from the cement production process for district heating in the area and is expected to send cold water from its own quarry for district cooling to a new regional hospital. Table 2 summarizes our findings.

Table 2: Identified IS partnerships at Aalborg Portland

Resources exchanged through IS		Source	Acts as a substitute/complement of	Proximity of partner
Alternative Fuels	1. Dried sewage sludge	Wastewater treatment plant	Conventional fuel (either bituminous coal or petroleum coke)	Local
	2. Meat and bone meal	Animal fodder producer		National
	3. Waste from industry (RDF - refused derived fuel)	Diverse waste collection schemes		Local/International
Waste Materials	4. Desulphurization gypsum	Power station	Natural gypsum	Local
	5. Fly ash		Alumina-containing materials (e.g. clinker, cement)	Local/International
	6. Sand	Dredged from fjord	Excavated sand	Local
	7. Iron oxide	Sulphuric acid factory	Pyrite ash (source of iron)	International
	8. Paper sludge	Paper recycling factory	Conventional fuel, chalk and fly ash	National
	9. Aluminium by-products	Aluminium recycling factory	Aluminium, fly ash	International
	10. Bottom ash	Biomass-fired power plants	Conventional fuel, fly ash	Local
Energy	11. Excess heat	City district heating grid	District heating from non-renewable sources	Local
Water	12. Excess cold water	Newly built regional hospital (planned)	The need to operate electrical AC-units	Local

As seen in Table 2, the largest number of ongoing IS partnerships are established with local partners. Several definitions of IS point at the necessity that IS partnerships should occur in a relatively close geographical proximity (Chertow, 2000), while geographical proximity is also proven by plentiful examples not to be a critical prerequisite (Lombardi *et al.*, 2012). Even though not a precondition for IS partnerships (Lombardi and Laybourn, 2012), geographical proximity has been identified in IS literature as beneficial for the exchange of tacit knowledge (Velenturf and Jensen, 2016). Combined geographically proximate and distant IS partnerships, though, have shown to sparkle innovation (Mirata, 2004).

Aalborg Portland has selected those IS partners situated in the surrounding area based on various motives. Firstly, due to the quantities of exchanged materials and fuels (approx. 600,000 tons), long distance transportation is considered neither cost efficient nor environmentally preferred. Waste from industry and

aluminum by-products are sourced non-locally since no material of high enough quality can be obtained from the surrounding industries.

Secondly, Aalborg Portland has the ambition to promote local sustainable development and thus bases a considerable part of its production on recycling material flows from the surrounding society. The IS partnerships result in lower environmental impact from transportation, as the virgin materials otherwise used would have been sourced from significantly longer distance. Lastly, the cement producer acknowledges the importance of interaction with regional external partners, as that can lead to innovating through development of greener production methods and expanding their product portfolio. More specifically, the company is currently developing a new “greener” product in collaboration with research institutes and industry, which will include alternative cementitious materials, require less energy and emit less CO₂.

4.2 Linking the IS partnerships to CE

The conceptual model of CE, presented through Ellen MacArthur’s “Circular economy system diagram”, is used to identify which product life cycle stage the exchanged wastes and by-products derive from and which loop they influence. Figure 3 illustrates how the IS partnerships link to CE.

Five of the IS partnerships of our company case were found to enable CE through recycling of wastes and by-products, linking to the most outer loop of the “Circular economy system diagram”, namely ‘recycling’. This is the case with dried sewage sludge, waste from industry, sand, paper sludge and aluminium by-products, all wastes and by-products of diverse ‘end-of-life’ products.

We identified the presence of two additional loops in the “Circular economy system diagram”, linking back resources from product manufacturer to material/parts manufacturer through ‘recycling’ and ‘reuse’. Meat and bone meal, desulphurization gypsum, fly ash, iron oxide and bottom ash are five wastes and by-products generated during the production phase of respectively animal fodder and energy. They are recycled by re-introducing them as alternative fuels or raw materials in the cement production and belong to the ‘recycle’ loop between product manufacturer and materials/parts manufacturer. Excess heat is considered a secondary output from the kiln process of cement production,

utilized by the local district heating system. Thus, the excess heat from the cement manufacturer is reused at input for other processes and results in a new ‘reuse’ loop. Excess cold water, though, is not considered part of this ‘reuse’ loop as it derives already at the raw material sourcing stage. When limestone is extracted from the nearby quarry, groundwater rises to the surface and can be utilized directly for district cooling without much further treatment.

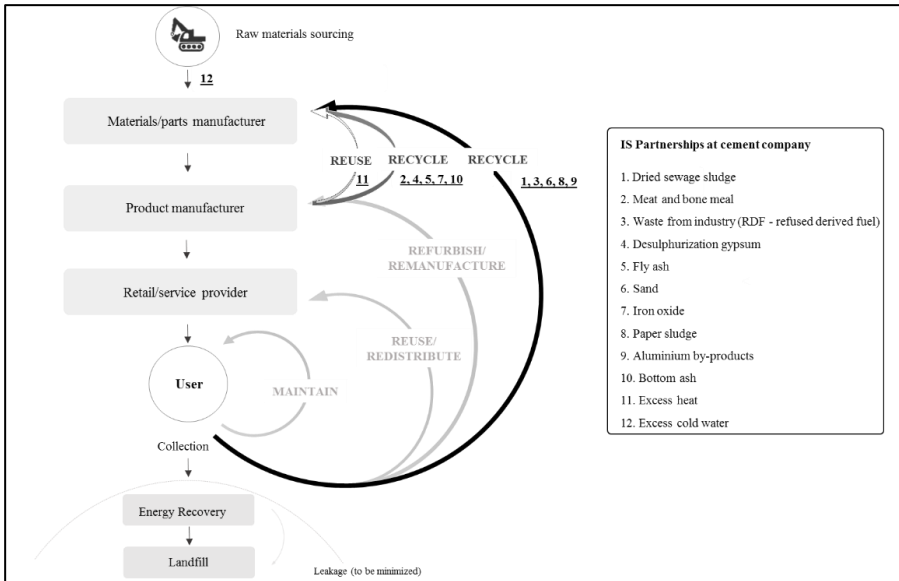


Figure 3: The IS partnerships at the cement company and how they are linked to CE

4.3 Improving resource efficiency through IS partnerships

As evident from this study, IS partnerships in the case of cement currently enable mainly the ‘recycling’ loops, which brings less value than the inner loops, such as ‘reuse’ or ‘remanufacturing’. Nevertheless, we acknowledge that especially in energy-intensive industries, such as the cement, even a small step in modifying the material and fuel mix with wastes and by-products can lead to significant environmental, economic and social benefits – a cornerstone in the notion of CE.

The global CO₂ emissions associated to cement production have a potential to significantly decrease due to the utilization of waste and by-products by the industry (Miller *et al.*, 2017). The IS partnerships of the case company were found

to lower the overall environmental impact of cement production. The cement company utilizes about 2,600 TJ from alternative fuels, sends about 1,200 TJ of excess heat and uses 450,000 tons of alternative raw materials, translating savings of about 430,000 tons CO₂-eq/year (Sacchi, 2018). According to the collected data from our company case, one of the reason is that a large number of the alternative resources are considered carbon-neutral, since the emissions associated to them are linked to the primary purpose they serve. Nonetheless, the impacts of the alternative resources are proven to be lower compared to traditional raw materials and fuels (Habert *et al.*, no date). Additionally, an earlier study on the district heating sources in the area points at potential for the cement company to double its excess heat delivery to the district heating grid, which would lead to more than 90% reduction in the carbon footprint of the heat in the heating system (Sacchi and Ramsheva, 2017).

Alternative raw materials and fuels has already been used by a large number of cement plants especially in Europe, however (Aranda Usón *et al.*, 2013) points at the still untapped potential for cement companies. From an economic perspective, additional infrastructure for storing and processing the received alternative resources is required, also reflected by our company case. For example, the cement company had to invest in two silos and a feeding system to the kiln, in order to utilize meat and bone meal as alternative fuel. Nevertheless, both our interviewees and studies on cement production point out that possibilities for reducing costs of fuels and materials can bring the highest savings for cement companies (Aranda Usón *et al.*, 2013).

4 Conclusion and limitations

This study demonstrates the link between IS and CE by examining twelve IS partnerships of Aalborg Portland, a large cement producer in Denmark and discussing how they relate to the loops of Ellen MacArthur's "Circular economy system diagram". IS plays a role in closing the CE loops, but there exists no one-size-fits-all approach for industries. In the case of cement, it is currently hard to trace the end-product back to the producer since cement is an ingredient of concrete. IS partnerships of our case company enable mainly the recycling loop of other materials. Recycling of end-products and materials represents the most outer circular loop and does not offer the most resource efficient solution in a circular context. That is partially due to the fact that as part of the energy-

intensive sector, cement requires a vast amount of energy and resources in the production process, and utilizing alternative fuels and materials is a way to lower CO₂ emissions from production. The direct reuse of resources in the context of cement production is also possible and exemplified by the “excess heat” IS partnership between the cement producer and the local district heating system. Nevertheless, we highlight the importance of the cement industry to direct its attention towards the more inner circles of the CE where more resource value can be captured. Such a focus may require going beyond the borders of the cement production plant, following the product life cycle of cement towards concrete production facilities and construction companies responsible for infrastructure projects. Though technically difficult and currently not economically feasible, in principle, it is possible to recycle concrete and reuse concrete elements. Today most concrete demolition waste is recycled as aggregate for new concrete or backfill for road construction, replacing virgin aggregate. However, there is need for further research to analyse this topic in more detail.

Furthermore, the current trend of utilizing wastes and by-products from certain processes, for example energy production from coal power plants, could be considered a potential future concern. The reason is that in Denmark, and in other countries, energy sourced from coal is being slowly, but gradually phased out. That brings future uncertainty of alternative raw materials supply for the cement industry, but also gives stimuli to continuously look for alternatives in terms of the materials and fuels the cement industry can source and utilize in its production. We suggest a further investigation of that trend, looking more specifically for future availability of certain waste and by-products.

On a broader context, this study opens up for a wider discussion on the development of inter-company networks for the exchange of resources, i.e. materials, by-products, even knowledge. In an economy with limitless industrial activities and by-products generated, there is a need to either establish more structured IS programs, such as the well-known the National Industrial Symbiosis Program (NISP) in UK, or encourage self-driven eco-industrial initiatives, the case of Kalundborg symbiosis (Boons, Spekkink and Mouzakis, 2011). In either case, such IS initiatives should encourage companies to connect and work as an ecosystem, identify possibilities for resource exchange and innovation, and thus enable CE. Both public and private industrial partners

should be involved in such IS partnerships, the exchanges should not be limited by physical materials and by-products, but also include information and knowledge. Inter-company collaboration through establishing IS partnerships has been identified as way towards innovation and creating a positive impact for both economy, society and environment (Mirata and Emtairah, 2005). Still, we recognise the need for further research to explore what the effect of those IS networks is from a regional and local perspective.

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