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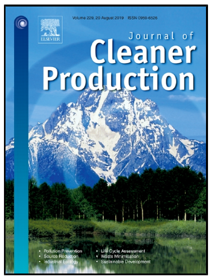

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Managing waste quality in industrial symbiosis: insights on how to organize supplier integration

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ABSTRACT
Reusing waste materials of other industries, a practice known as industrial symbiosis, attracts growing attention by industry. However, the waste materials are often of lower quality than the virgin materials they substitute. When production processes are intolerant for lower quality materials, production issues may occur. This paper sets out to explore how firms can manage the waste quality through supplier integration with the waste supplier. As suppliers have to learn new knowledge, the construct of absorptive capacity is used as an interpretive lens. An in-depth longitudinal exploratory case study approach is used to examine the involvement of different individuals and departments in the supplier integration activities in the context of the waste-based fuel supply chain of a global cement producer. Qualitative and quantitative data was gathered at both the buyer and the supplier. The data show that buyers can increase the absorptive capacity of the suppliers by aligning their own knowledge bases with the scope of the supplier integration. The increased absorptive capacity enables the suppliers to align waste quality with production requirements. Managing waste quality is an important capability of industrial symbiosis, especially when firms want to go beyond the low-hanging fruits and increase the effectiveness of their industrial symbiosis activities. The research concludes with theoretical and managerial insights into how firms can organize the supplier integration to manage waste quality in the context of industrial symbiosis.

Keywords: Supplier integration; industrial symbiosis; waste; process industry; supply chain, absorptive capacity.

1. Introduction

This research takes its outset in a real-life case that the authors encountered during a research project at a cement manufacturer who is deeply engaged in industrial symbiosis – i.e. the practice of using waste and byproducts of other industries. After having captured the low-hanging fruits, the cement manufacturer aimed to increase the volume and the scope of their symbiotic activities. However, to maintain high final product quality and high operational efficiency in a production environment which is designed and optimized for the use of virgin materials, the waste products need to conform to exacting quality standards. To manage the until now poor and varying quality of the waste, the cement manufacturer engaged in supplier integration (SI): the exchange of information by means of reports, calls and e-mails as well as visits to each other. The SI intended to align the quality of waste with the production requirements. However, the SI did not give the intended result, even though supply chain literature suggests a positive relationship between SI and supplier performance (Frohlich and Westbrook, 2001) such as the quality of the materials delivered by the supplier (Huo et al., 2019). Instead, the supplier indicated not to understand how to align the waste quality with the production requirements. Yet, SI is considered important in the context of industrial symbiosis (Zeng et al., 2017) and the wider field of the circular economy (Masi et al., 2018).

To manage the quality of the waste, the supplier needs to know what waste quality entails. However, the context in which many industrial symbiosis practices unfold complicates defining waste quality and developing suitable incentives for waste quality (Yenipazarli, 2019). Case descriptions of industrial symbiosis show that industrial symbiosis often takes place in the process industry – see for example the industrial symbiosis in Chamusca in Portugal (Costa and Ferrão, 2010), Rotterdam in The Netherlands (Baas and Boons, 2004), Ulsan in South in South Korea (Behera et al., 2012) and the National Industrial Symbiosis Programme in the United Kingdom (Mirata, 2004). In fact, the MEASTRI Exchanges

Database (Evans et al., 2017) – a comprehensive database describing symbiotic exchanges from all over the globe – shows that 71% of the buyers of waste and 75% of the suppliers of waste are process industries (Prosman, 2018). The process industry is characterized by high internal manufacturing complexity (King, 2009) which is defined as 'the level of detail and dynamic complexity found within the manufacturing facility's products, processing, and planning and control systems' (Bozarth et al., 2009, p. 80). The process industry's high internal manufacturing complexity arises from the difficulty of measuring where and why production inefficiencies occur due to 1) the interlinked processes with no or only limited intermediate storage (Van Donk and Van Dam, 1996) and 2) the random variation happening in the highly interlinked processes such as temperature and pressure variances (King, 2009). In the context of industrial symbiosis, the high internal manufacturing complexity may lead to a complex relationship between waste quality and operational parameters and subsequently, may create ambiguity about what waste quality entails (Pires et al., 2019).

Managing waste quality by means of supplier integration

Extant literature is concerned with optimizing supply strategies considering various external factors towards green supply chains (Qu et al., 2019). In this perspective, SI aims to improve supplier performance through enabling effective and efficient flows of products, information, services and decisions (Feyissa et al., 2019)). Supply chain literature suggests a positive relation between SI and supplier performance – see for example the seminal study on the effect of SI by Frohlich and Westbrook (2001). SI is especially effective when supported by internal integration (Zhao et al., 2011) which helps firms to process the input and output of SI (Schoenherr and Swink, 2012). Prosman et al. (2017) suggest that internal integration, as support for SI, is important in the context of industrial symbiosis.

In practice, in a manufacturing context where internal integration supports SI, knowledge travels along the following or a similar path. First, knowledge about quality requirements travels via internal integration from the buyer's operations department to the buyer's purchasing department. Next, the knowledge travels via SI to the supplier's sales department. The supplier's sales department, in turn, passes the knowledge on to their operations department via internal integration. The supplier's operations departments, ultimately, transform and exploit the knowledge to align product quality with the buyer's requirements (Das et al., 2006).

Conveying complex information, as needed to manage waste in the context of industrial symbiosis, requires interactive SI approaches such as face-to-face meetings, rather than more vicarious and passive SI approaches like Electronic Data Interchange systems and the exchange of performance evaluations (Huber, 1991).

In sum, current literature suggests the SI as depicted in Figure 1 in the context of managing waste quality in a setting of high internal manufacturing complexity.

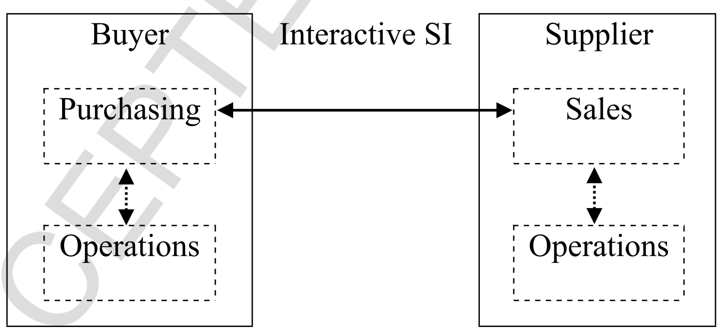

Fig. 1. SI in the context of managing waste quality in a setting of high internal manufacturing complexity as suggested by current literature. Dotted arrow: internal integration; solid arrow: interactive SI.

To acquire and to not miss out on valuable knowledge, suppliers benefit from a high understanding of the buyer's processes and products because it creates awareness of the requirements for potential improvements (Setia and Patel, 2013). A lack of knowledge about the buyer's processes and products may hinder the supplier in extracting the meaning of the exchanged knowledge (Zahra and George, 2002) and to manage the waste quality accordingly. Hence, employing interactive SI approaches supported with internal integration in itself may not enable suppliers to learn and, therefore, to align waste quality with the buyer's production requirements.

Absorptive capacity

The theory of absorptive capacity provides an appropriate lens to explain how SI enables companies to manage waste quality. Absorptive capacity, as defined by Cohen and Levinthal (1990) in their seminal paper, refers to the ability to 'recognize the value of new, external information, assimilate it, and apply it to commercial ends' (Cohen and Levinthal, 1990, p. 129). Hence, absorptive capacity succinctly captures the capabilities needed for knowledge transfers to manage waste quality.

Absorptive capacity is a firm-level construct which relies upon the individual units of knowledge available within the firm as well as the efforts expended by the firm and their employees to utilize this knowledge (Cohen and Levinthal, 1990). The individual units of knowledge refer to the employee's ability, their educational background and their job-related skills (Cohen and Levinthal, 1990). Following the seminal work of Zahra and George (2002), efforts to enhance the absorptive capacity can address two separate but complementary dimensions. First, potential absorptive capacity (PAC) creates knowledge through *acquiring* and *assimilating* relevant knowledge. Second, realized absorptive capacity (RAC) utilizes PAC through *transforming* and *exploiting* knowledge. So, PAC precedes RAC (Zahra and George, 2002). Table 1 provides a description of the supplier's PAC and RAC in relation to SI aimed at managing waste quality.

Table 1

Dimensions of absorptive capacity of suppliers in relation to managing waste quality through SI

Dimensions	**Sub-dimensions (Zahra and George, 2002)**	**Relation to managing waste quality through SI (adjusted from Setia and Patel (2013)**
PAC – create knowledge	Acquire	The capacity of the supplier to identify and gather relevant knowledge via SI for managing waste quality.
	Assimilate	The capacity of the supplier to internalize and comprehend the acquired knowledge required for managing waste quality.
RAC – utilize knowledge	Transform	The capacity of the supplier to combine existing knowledge with the newly created knowledge to identify opportunities to manage waste quality better.
	Exploit	The capacity of the supplier to leverage existing competencies and to create new competencies to manage waste quality.

The unit of analysis of the construct of absorptive capacity has evolved over time. In their seminal paper, Cohen and Levinthal (1990) view absorptive capacity as a firm-level construct by arguing that absorptive capacity is an ability which firms develop over time by accumulating a relevant knowledge base based on the knowledge of the employees. However, Lane and Lubatkin (1998) propose a dyadic (relational) rather than a firm-level unit of analysis. They argue that absorptive capacity in terms of acquiring new knowledge is determined by the relative relationship between the knowledge bases of the involved firms – the student firm (typically the supplier) and the teacher firm (typically the buyer). The overlap between the knowledge bases of the student firm and the teacher firm, together with interaction routines such as SI, largely determines the absorptive capacity of the student firm (Lane and Lubatkin, 1998). Hence, a firm's absorptive capacity may differ depending on the firm they are collaborating with; when the SI takes place between a buyer and a supplier with overlapping knowledge bases, the SI will be more efficient. Recent literature on absorptive capacity adopts Lane and Lubatkin's (1998) dyadic unit of analysis, see for example the research of Park and Chung (2019) on how knowledge can be transferred to subsidiaries.

Aligning the relative relationship of knowledge bases in the context of industrial symbiosis and high internal manufacturing complexity

As mentioned, SI in the context of industrial symbiosis in the process industry is often characterized by high internal manufacturing complexity. Whether the complexity constraints the SI depends on the knowledge of the involved individuals. Cognitive decision-making literature distinguishes between objective and perceived complexity (Campbell, 1988). *Perceived* internal manufacturing complexity is *not* a linear function of the complexity found in a facility's products, processing and planning and control systems (Manuj and Sahin, 2011). Instead, the knowledge of individuals may lead to low perceived complexity in cases of high objective complexity, i.e. what is perceived as complex by one person may not be perceived as complex by another person (Manuj and Sahin, 2011). Therefore, SI in a context with high objective complexity, such as industrial symbiosis in the process industry, may benefit from aligning the knowledge bases of individuals and departments with the scope of the SI since individuals with relevant knowledge bases may perceive the complexity as being lower (Wong et al., 2015).

In fact, employees and departments within the same firm may have different knowledge bases (Galbraith, 1973), such as purchasing and operations (Swink and Schoenherr, 2014), and can therefore respond differently to complex issues (Turner et al., 2019. For example, purchasing managers may have limited knowledge about the impact of waste on production processes. Moreover, the bounded rationality of individuals may keep them from obtaining knowledge about all relevant aspects (Simon, 1991). The buyer's procurement and the supplier's sales department may therefore perceive operational knowledge about the impact of waste on production as highly complex due to their bounded rationality and limited operational knowledge. Knowledge about manufacturing processes and products arguably resides within the operations departments, which may lower the perceived internal manufacturing complexity in these departments. So, SI aimed at managing waste quality may benefit from involving operations departments at both the buyer and the supplier in the SI. When the knowledge bases of the individuals and/or departments are aligned with the scope of the SI, we coin the SI 'aligned SI'; opposed to 'misaligned SI' where the involved knowledge bases of the individuals and/or departments are not aligned with the scope of the SI. Figure 2 illustrates this.

		Supplier	
		Involved individuals / departments possess relevant knowledge about the impact of waste on production	Involved individuals / departments do not possess relevant knowledge about the impact of waste on production
Buyer	Involved individuals / departments possess relevant knowledge about the impact of waste on production	A - Aligned SI	B - Misaligned SI
	Involved individuals / departments do not possess relevant knowledge about the impact of waste on production	C - Misaligned SI	D - Misaligned SI

Fig. 2. Aligned and misaligned SI

Note, aligned SI does not necessarily lead to the involvement of operations managers. Purchasing managers, for example, can still engage in aligned SI when their knowledge about operations is sufficient for the SI. Moreover, sometimes odd relationships can facilitate new insights and angles to a problem which individuals with similar outsets would not identify. Aligned SI may therefore not help in managing waste quality. In addition, aligning the SI alone may not be enough to align waste quality with production requirements. Other conditions may impact the SI as well such as power imbalances, relationship management and the depth of the integration (Prosman et al., 2016).

Research question

Aligning waste and byproducts properties with production requirements may require efforts from the supplier such as separating certain waste fractions and mixing in other materials (Duflou et al., 2012). SI seems promising in supporting the supplier in performing the right efforts. However, literature says little about organizing the SI under different business conditions such as industrial symbiosis – regardless of a call for such literature (Kleindorfer et al., 2005) and the acknowledgement that industrial symbiosis has a different context than other buyer-supplier relationships (Bansal and McKnight, 2009). More recently, Herczeg et al. (2018) concluded that supplier integration is important for waste and byproduct treatment and that more research is needed on this topic. However, despite the large body of SI literature, the relationship between SI and who – at an individual or departmental level – is involved in SI in the context of industrial symbiosis remains largely unexplored and no clear-cut managerial implications have emerged (Wong et al., 2015). By building upon a case where there is a shift from misaligned SI (quadrant C in Figure 1) to aligned SI in a context with high internal manufacturing complexity, this paper explores the following research question: *how and why does misaligned and aligned SI enable suppliers to manage waste quality in the context of high internal manufacturing complexity?*

Figure 3 below provides the conceptual model of this study. As presented above, SI enables firms to manage the quality of the waste. However, the perceived complexity of the SI affects the degree to which SI enables the management of waste quality. The perceived complexity is affected by the absorptive capacity of the individuals involved in the SI. The absorptive capacity can be increased by involving individuals and departments based on their knowledge about the scope of the SI.

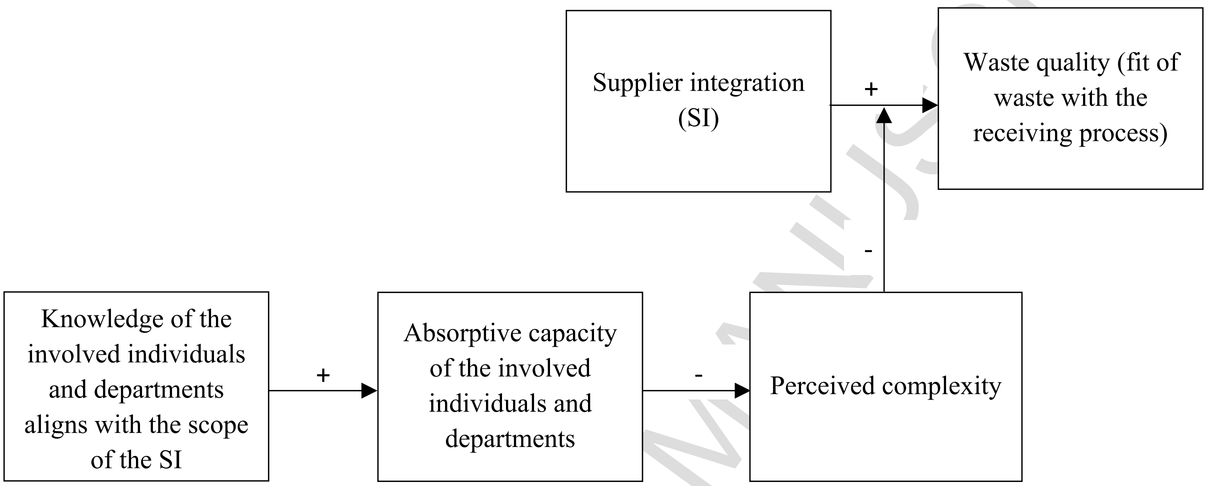

Fig. 3. Conceptual model of the study

Answering the research question contributes to literature in the following ways. First, although absorptive capacity has been studied in buyer-supplier relationships in the manufacturing sector – see for example the study of Nagati and Rebolledo (2012) on improving supplier performance, the study of Rojo et al. (2018) on making the supply chain more resilient and the study of Zhang et al. (2018) on product innovation – contextual factors have so far been neglected and benefit from inclusion (Lane et al., 2006). Second, the insights of this study help firms in industrial symbiosis to align waste quality with production requirements (Herczeg et al., 2018), thereby contributing to progressing towards cleaner production (Meneghetti and Nardin, 2012).

Methodology

This paper adopts an in-depth longitudinal single case study to explore the research question. A case study design is appropriate due to the reliance on the ability of qualitative data to gain a holistic and in-depth understanding of the *how's* and *why's* of the cause and effect between the phenomena of aligned and misaligned SI, objective and perceived internal manufacturing complexity and absorptive capacity (Eisenhardt, 1989). Moreover, the complex context of this study – i.e. high internal manufacturing complexity and the role of absorptive capacity – renders a case study approach particularly suitable (Stuart et al., 2002).

The longitudinal approach allows to explore the effect of the shift from misaligned SI to aligned SI on the absorptive capacity and the effect on waste quality whilst guarding against problems with retrospective data – e.g. not recalling important events and post-rationalization (Eisenhardt and Graebner, 2007). Furthermore, the active presence in observing the phenomena provides access to rich data denied by other approaches (Voss et al., 2002). In addition, a longitudinal approach reduces (but not necessarily removes) the risk of misjudging an event and exaggerating easily available data (Eisenhardt and Graebner, 2007).

Case introduction

The study is conducted in the context of industrial symbiosis in the cement industry, where 'Cema', a cement manufacturer, procures waste-based fuel from 'Marp', a material recovery plant. Cema is a large and globally operating cement manufacturer and the plant under investigation is among the largest and most complex cement plants in the world. Marp is a key supplier of Cema since waste-based fuel is of strategic importance for Cema due to the environmental pressure from outside and the large share of waste-based fuel delivered by Marp (>40% of the total waste-based fuel supply to Cema). Cema started to procure waste-based fuels at Marp after Marp was acquired in 2015 by the same holding company also owning Cema. Although Cema and Marp continued to operate as separate entities, both firms operating under the same flag offers a suitable context to explore the research question as it reduces the impact of mitigating and moderating factors beyond the scope of the research such as a fear for greater dependence (Williamson, 1982) and power erosion due to increased information sharing (Kähkönen, 2014).

The shift from misaligned to aligned SI between Cema and Marp offers fertile ground to gain insights into the research question. Although seemingly simple, the use of waste-based fuel in the cement industry is subject to high objective internal manufacturing complexity for two reasons. First, it is difficult to measure the impact of waste-based fuel quality on cement output since complex interactions between various other operational parameters determine the cement output. Second, Marp's waste-based fuel consists of a heterogenous and continuously changing mix of materials which makes it difficult to pinpoint which aspect of the waste-based fuel causes production inefficiencies. Indeed, a number of (engineering) studies show the objective internal manufacturing complexity of waste-based fuel usage in cement production, see for example Summerbell et al. (2016). Hence, except for some straightforward quality aspects, managing the quality of waste-based fuels in the cement industry is subject to high objective internal manufacturing complexity. In line with the research objective, this paper focuses on the complex waste quality requirements rather than the obvious ones such as energy content.

Data collection

To explore the research question and to understand the complex context, data was collected from multiple sources to capture a wide variety of perceptions and meanings (Jick, 1979). In doing so, this paper follows Pettigrew's (1990) approach on theory building by progressing through two stages from collecting surface-level data towards collecting detailed data.

In the first stage – between January 2016 and September 2016 – surface-level data was gathered to allow the researchers to become ultimately familiar with the case and to understand the internal manufacturing complexity deriving from the use of waste-based fuel. To do so, the first author spent two to three days per week at Cema's operations and procurement departments as well as a total of five days at Marp's operations departments. During this period, the first author attended meetings regarding waste-based fuel quality. In addition, unstructured interviews, with no predetermined questions, were held with all employees involved in the SI (see table 2) focused on understanding the entire operational processes and the occurring problems related to alternative fuel usage within Cema and Marp. During the meetings and the unstructured interviews, notes were taken. Also slides of presentations and internal memos related to the research question were collected. The first stage ended when the researchers felt confident that they had an in-depth understanding of the context in which the research question took place: an overview of the supply chain and operational challenges of using alternative fuel, a clear insight into how SI between Cema and Marp takes place and an understanding of the internal manufacturing complexity.

In the second stage, the obtained surface-data from the first stage was used to conduct semi-structured interviews with employees from both Cema and Marp. The questions focused on the difference between aligned and misaligned SI and how this related to managing waste quality in a context with high internal manufacturing complexity. The surface data gathered in the first stage aided in selecting the interviewees and to ask them relevant questions about their role in the SI. The interviewees were selected based on their expertise and involvement in the SI (see table 2). The semi-structured interview protocol consisted of broadly defined themes with open-ended questions which focused on the content of the SI, the role of the different dimensions of absorptive capacity and the effect on managing waste-based fuel quality. During the semi-structured interviews, the interviewees were probed to come up with detailed responses. The rich data deriving from the interviews facilitated data comparison between misaligned and aligned

SI (Yin, 2009). The semi-structured interviews lasted on average about one hour and were recorded and transcribed verbatim. In addition, written communication such as e-mails and documented correspondence in the Enterprise Resource Planning (ERP) system about alternative fuel quality rendered additional insights in the performance of both types of SI. Furthermore, hour-by-hour production data was collected from Cema's production system. This data was used to estimate the effect of alternative fuel on production capacity (poor waste-based fuel quality reduces production capacity) whilst controlling for non-waste-based fuel related factors – see data analysis. Improved production efficiency because of alternative fuel is a proxy of effective SI and serves to determine whether aligned SI is more effective than misaligned SI. In addition, data on production downtime related to waste-based fuels of Marp was collected for the periods before SI, during misaligned SI and during aligned SI. The collection of multiple and supplemental data increased the construct validity of this study (Yin, 2009).

Table 2

Overview of interviewees

Firm	Interviewee	Unstructured interviews*	Semi-structured interviews**	Interviewee's relation to misaligned SI	Interviewee's relation to aligned SI
Cema	Operations manager A	14	2	Communicate quality data to Cema's procurement	Communicate quality data to Marp's operations
	Operations manager B	5	1	“”	“”
	Purchaser	5	1	Acquiring quality data from operations and communicate this to Marp's operations	N/A
	Category manager	8	0	“”	“”
	Operational excellence manager	6	2	Supporting Marp in managing quality	Supporting Marp in managing quality

	Supply chain manager	5	1	Responsible for overall relationship	Responsible for overall relationship
	Strategic sourcing manager	3	1	“”	“”
Marp	CEO	4	1	Responsible for overall relationship	Responsible for overall relationship
	Operations manager A	6	2	Acquiring quality data from Cema’s procurement and assimilate, transform and exploit this data	Acquiring quality data from Cema’s operations and assimilate, transform and exploit this data
	Operations manager B	3	2	“”	“”
Total		59	13		

* Notes were taken

** Interviews are recorded and transcribed verbatim

Data analysis

Data was analyzed through a first- and second-order analysis. During the first-order analysis, statements as expressed by the employees involved in the SI in interviews, e-mails and correspondence documentation in ERP were coded (Gioia and Chittipeddi, 1991). The codes related to concepts that clearly related to the research question 'how and why aligned and misaligned SI enables suppliers to manage complex aspects of input quality in the context of high objective internal manufacturing complexity?' and the absorptive capacity lens. For example, "*we had limited knowledge about what was needed*" was coded as 'lack of exploitative capacity' and the quote from an interview after the shift to aligned SI "*it was a mess, but now we know where the targets are, where the KPIs are*" was coded as 'improved acquiring capacity'.

During the second-order analysis, the outcomes of the first-order analysis were used to search for an explanatory framework for the research question (Gioia and Chittipeddi, 1991). The aim was to identify connections between misaligned and aligned SI and the effect on the different dimensions of absorptive capacity of Marp to manage complex aspects of waste-based fuel quality. During this analysis, a recursive and iterative approach was balanced with early structure by linking the outcomes of the first-order analysis to constructs of the existing theory of absorptive capacity – e.g. acquiring and assimilating relevant information enables knowledge creation. Furthermore, production data was analyzed to test the effect of the improved alignment of the complex aspects of waste-based fuel quality and production requirements based on the output rate of production. To do so, the collected production data was divided into three groups: 'before SI', 'misaligned SI' and 'aligned SI'. To isolate the effect of waste-based fuels from Marp, days where the output rate was affected by non-waste-based fuel related issues was controlled for. Moreover, also periods where fossil fuels or waste-based fuels from other suppliers were used was controlled for. Furthermore, data from the first month after the implementation of misaligned and aligned

SI was discarded to allow for an implementation period (the implemented changes did not require significant changes) and the delays due to the shipping time of waste-based fuel. For the remaining data, the effect of waste-based fuel on the hourly output rate of production was tested by conducting a one-way analysis of variance (ANOVA) with post-hoc multiple comparison tests (Tukey) for the periods 'before SI', 'during misaligned SI' and 'during aligned SI'. Prior to the ANOVA, the data analysis tested for outliers, normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test for homogeneity of variances). As none of the assumptions of ANOVA were violated, the data analysis could proceed with the ANOVA test (Hair et al., 2009). The production figures are indexed for confidentiality reasons.

Next, peer debriefing – i.e. engaging researchers that are not involved in the research – to discuss emerging connections in the data was used. Moreover, preliminary versions of the findings were presented at Cema and Marp to discuss the interpretations and the explanatory framework. These discussions proved helpful in both finetuning the insights and in assessing the internal validity of the findings. Throughout the data analysis process, NVivo was used to manage the data, to facilitate an overview of the codes and the chain of evidence, thereby increasing the reliability and validity of the findings (Yin, 2009). All statistical tests were carried out in R. Figure 4 provides a detailed overview of the data collection and data analysis.

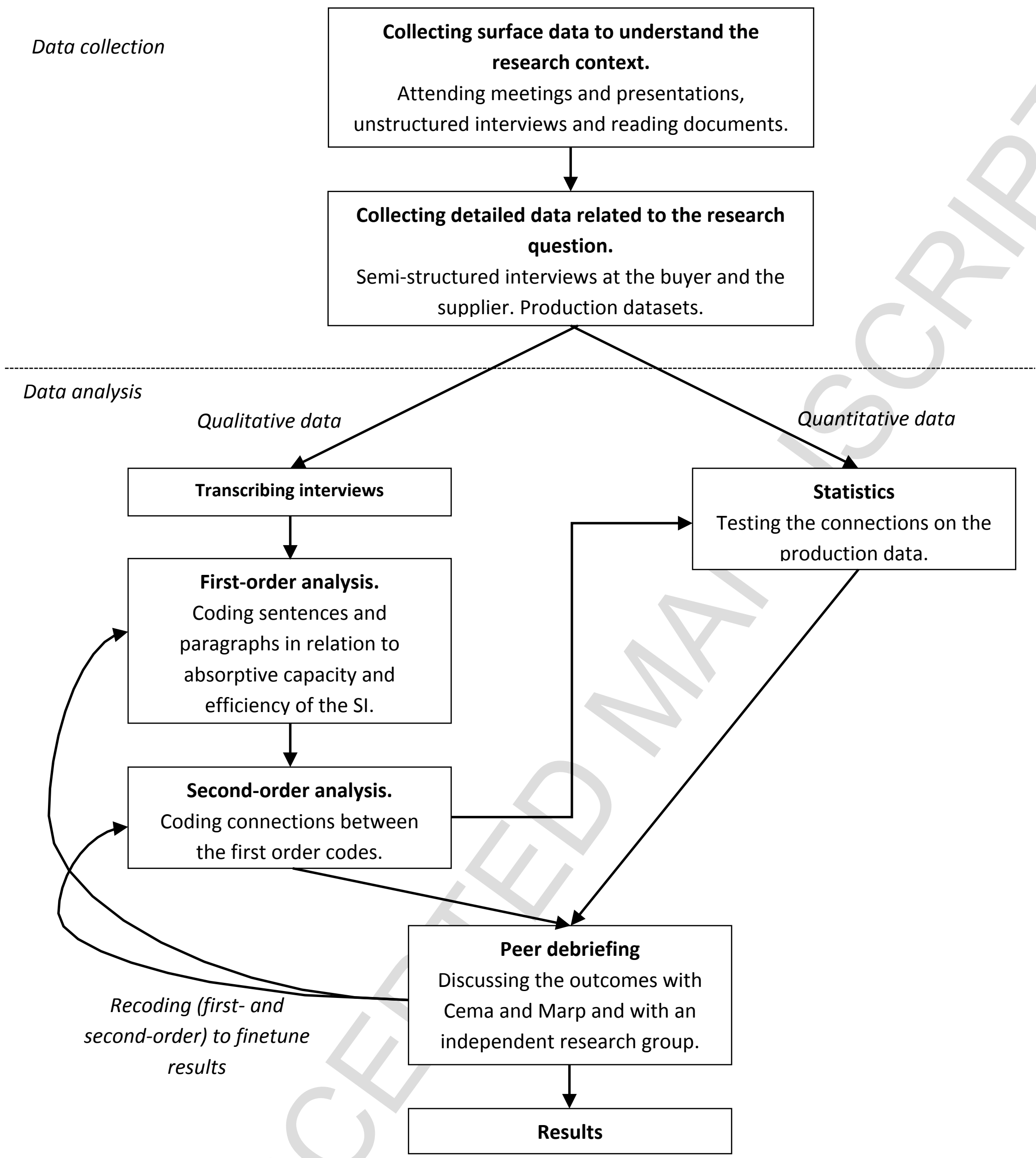

Fig. 4. Framework with detailed steps of the data collection and data analysis

Findings

This section describes the misaligned and aligned SI between the buyer – Cema – and the supplier – Marp. For both types of SI, this section describes how SI took place, how SI affected Marp's absorptive capacity and Marp's ability to manage the waste quality. Table 3 – at the end of this section – provides a quantitative perspective on the effect of misaligned SI and aligned SI on waste-based fuel quality based on production data.

Misaligned SI

In early 2016, Cema and Marp embarked on SI to align waste-based fuel quality with production requirements as waste-based fuel caused several issues at production. The SI took place through phone calls, written communication and the exchange of fuel specifications and fuel analysis reports between Cema's procurement department and Marp's operations departments. Furthermore, Cema's procurement representatives and Marp's CEO and operations managers visited each other to discuss how to manage waste-based fuel quality. Cema's operations department provided Cema's procurement representatives with access to accurate and relevant information. However, the SI did not render the desired result as the limited knowledge of Cema's purchase managers limited the absorptive capacity of Marp's operations managers. The following paragraphs present the findings in more detail.

The knowledge base of Cema's procurement department was misaligned with the scope of the SI – i.e. aligning the quality of alternative fuel with Cema's production requirements. Cema's procurement department acquired relevant knowledge from the operations department in the form of quality reports and face-to-face meetings in which operations managers explain how waste-based fuel quality affects cement production. However, despite the access to knowledge, Cema's procurement department struggled to understand waste-based fuel quality requirements and the impact on production. As Cema's operation manager (A) explains: "*it is difficult for them [Cema's procurement department] to understand the issues that it [the poor quality of certain aspects of the alternative fuel] can give us*". Similarly, but from a procurement perspective, Cema's supply chain manager points out: "*when they [Cema's operation managers] start to talk, I am directly out, it's too technical*". The low understanding results in ambiguity at Cema's procurement department about what alternative fuel quality entails. As Cema's purchaser mentions: "*we do not know what to measure*". Hence, the SI between Cema and Marp was misaligned due to the lack of knowledge at Cema's procurement department (see quadrant C of Figure 1 in the literature review).

The limited knowledge of Cema's purchasing department limited Marp's acquiring capacity and therefore limited Marp's PAC. Due to the poor understanding of waste-based fuel requirements in Cema's purchasing department, misaligned SI between Cema's procurement department and Marp's operations department did not contain relevant information. Operations manager A from Marp explains: "*They [Cema's procurement department] tell us [Marp's operations managers and Marp's CEO] that there is a problem with the quality, but there would not be any clarity towards what the problem is. They will just say there is a problem*". Documented correspondence between Cema and Marp confirms this: during the period of misaligned SI, quality issues are mentioned in vague terms in supplier correspondence (e.g. *"waste-based fuel caused problems with dust filters"* – ERP notification, October 2016). So, Cema's poor teaching skills led to misaligned SI and did not enhance the PAC, in particular the acquiring capacity, of Marp's operations managers.

The low PAC of Marp's operations managers limited them to align the waste-based fuel quality with Cema's production requirements. Operations manager A from Marp explains: "*There is no real clarity* *towards what the problem is. They [Cema's procurement department] will just say there is a problem, which makes it hard to resolve the issue, when you do not know what you are trying to fix*". Likewise, operations manager B from Marp stresses that the limited amount of information reaching Marp's operations managers limits Marp from assimilating how to manage the quality of the alternative fuel:

> "*we do not know what is important to them. A lot of the information coming into the company, it is information with little understanding … there is very little understanding of how their [Cema's] processes operate … So, we cannot improve our process. And we also cannot measure it when we do not know what is important… if they are not saying you need to be given it a little bit more of this, you need to do that, we are lost. We do not know what to do*"

The supplier correspondence in Cema's ERP system shows that Marp's response to vague improvement requests does not mention specific actions and typically resembles a '*we continuously try to improve the SRF [waste-based fuel]*' (response to aforementioned issue with the dust filters on October 2016). So, the low acquiring capability of Marp's operations managers limited their PAC and prevented them from aligning the waste-based fuel quality with Cema's production requirements. Production data confirmed that the waste quality was still not aligned with the production requirements, as such verifying the low performance of the SI, see table 3.

Aligned SI

In the summer of 2016, Cema directly engaged their operations department in the SI. Similar to the misaligned SI, the SI still took place through face-to-face meetings, phone calls, written communication and the exchange of quality documents and fuel analysis reports.

The involvement of Cema's operations managers led to aligned SI. First, Cema's operations department possessed knowledge about the scope of the SI – i.e. the quality of waste-based fuels. Furthermore, Marp's operations managers displayed a high understanding of Cema's processes when talking to Cema's operations managers: "*they [Marp's operations managers] understand what to do*" (Operations manager B, Cema). In addition, both Cema's and Marp's operations managers mentioned that they 'speak the same language' as they both have technical backgrounds. Hence, the new SI was aligned as the knowledge bases of both Cema's and Marp's operations managers were aligned with the scope of the SI.

The aligned SI between Marp's and Cema's operational functions increased the PAC of Marp's operations managers as it allowed them to acquire relevant information. As explained by operation manager A from Marp: "*it is good to see how the material is handled and used... we start to get a better understanding of what the issues are*". Furthermore, whereas the misaligned SI left Marp's operations managers in doubt about why and what to improve, the aligned SI clarified previously unclear communication: "*when you actually speak to them [Cema's operations managers] face-to-face or on the telephone, it is like 'no, no this is not what I meant, what I meant was…* '" (Operations manager B, Marp). So, aligned SI contributed to the PAC of Marp's operations managers by creating knowledge about what alternative fuel quality entails.

The increased PAC of Marp's operations managers allowed them to transform this knowledge by identifying how they can manage their processes and how they adapt their processes to align the waste-based fuel quality with Cema's production requirements. Operations manager A from Marp explains: "*we [Marp's and Cema's operations functions] were drawing out the supply chain and we were looking at what influences the material at each stage of the supply chain. And that was when it became apparent, when we handle material on site, by our current practices at the time, how the quality of the material* *was affected*". So, due to aligned SI, Marp's operations managers were able to transform information into improvement opportunities. Marp's operations managers subsequently exploited the new knowledge to align the quality of the waste-based fuel with Cema's production requirements. For example, Marp started to exclude certain waste streams since those waste streams created problems in Cema's processes. Moreover, specific investments in sorting equipment helped to align the waste quality with the requirements as well. Cema's operations managers confirm the improvements: "*the fuel of [Marp] does not create any problems anymore*" (operations manager B, Cema). Production data confirms the positive impact of the aligned alternative fuel quality on production capacity (see Table 3).

The results in Table 3 indicate that misaligned SI did not have a positive impact on production capacity in the case of low waste quality in the context of high internal manufacturing complexity. The production increase of 1.11% compared to the period before SI and the 1.24% increase compared to the period with unaligned SI can be attributed to the change in alternative fuel quality. The alignment of alternative fuel quality and production requirements allowed Cema to produce more cement. Although a seemingly small increase, such an increase is relatively large in cement production. In the case of Cema, where demand exceeds production capacity, the extra production capacity translates into significant profit gains. Furthermore, the kiln downtime related to waste-based fuel dropped with 44% after aligned SI – as such further increasing production capacity.

Table 3

Analysis of variance with Tukey post-hoc tests for the hourly indexed production figures for the periods before SI, with unaligned SI and aligned SI*

	Before SI (N = 1177)	Misaligned SI (N = 2110)	Aligned SI (N = 1632)	F. (Sig.)
Mean	100	99.87	101.11	35.791 ($p < 0.0001$)
95% Confidence intervals	99.42 – 100.57	99.34 – 100.39	100.88 – 101.33	
Mean difference before SI (Sig.)**	-	0.13 ($p \approx 0.722$)	1.11 ($p < 0.001$)	
Mean difference misaligned SI (Sig.)**	-	-	1.24 ($p < 0.001$)	

* The period before SI equals 100.

** Tukey multiple comparison, 1-tail test.

In addition, in the studied case, aligned SI led to creating new knowledge about waste-based fuel quality beyond the knowledge creation originally set out for. Discussions between the operations managers of both firms as well as site visits created additional knowledge about waste-based fuel quality. For example, it was identified that previously unused wastes or waste fractions could be used for cement production. Having this information allowed Marp to reduce cost by eliminating redundant waste separation steps and increase income by processing more types of waste.

Discussion

Current literature suggests that interactive SI supported by internal integration results in improved supplier performance (Zhao et al., 2011). This study challenges current literature as the findings suggest that, in the context of industrial symbiosis with high internal manufacturing complexity, this is not necessarily the case. Rather, the alignment of knowledge bases of the individuals involved in the SI, a concept coined as 'aligned SI', helps to understand how to organize the SI in the context of industrial symbiosis and high internal manufacturing complexity. The following sections discuss the findings in more detail by using the construct of absorptive capacity and linking it to SI performance in the context of industrial symbiosis and high internal manufacturing complexity.

The effect of absorptive capacity on SI performance

In the case under investigation, the SI centered around the complex quality aspects of waste-based fuel. The complexity ensued from the complexity of the production process, which made it unclear which aspects of the waste-based fuel impacted the production process.

Initially, the involved persons from Cema did not possess relevant knowledge about the impact of the waste-based fuel on production due to a lacking operational and technical background. Therefore, the SI was misaligned (quadrant C in Figure 2). As a result of the misaligned SI and the lacking knowledge of the individuals involved in Cema's side of the SI, Marp's operations managers did not acquire the necessary knowledge to manage waste-based fuel quality. The reduced knowledge acquiring capability of Marp's operations managers reduced their absorptive capacity and restricted them in aligning the quality of the waste-based fuel with Cema's production requirements. Therefore, in line with the construct of absorptive capacity, the first proposition is:

P1. Misalignment between the knowledge base of the buyer and the scope of the SI reduces the acquiring capability and thereby the absorptive capacity of the supplier.

Changing the individuals involved on Cema's side of the SI based on their knowledge of waste-based fuel quality enabled Marp to acquire the knowledge needed to manage the quality of the waste-based fuel. The acquired knowledge increased their absorptive capacity as it enabled them to exploit the knowledge and deliver the waste-based fuel in accordance with Cema's requirements. Hence, the second proposition is:

P2. Alignment between the knowledge base of the buyer and the scope of the SI increases the acquiring capability and thereby the absorptive capacity of the supplier.

The above two propositions suggest that absorptive capacity is a useful construct to understand how to organize SI in the context of industrial symbiosis characterized by high internal manufacturing complexity. As such, the first two propositions are congruent with previous research which holds that absorptive capacity is a useful construct for developing SI capabilities – see for example Vanpoucke et al. (2014). Moreover, the above two propositions provide additional insights into the field of SI. Interactive SI supported by internal integration alone is not enough to improve supplier performance: the alignment of knowledge bases may also play a significant role in improving supplier performance. Hence, prudent decisions, where firms align knowledge bases with the scope of interactive SI may enable the supplier to acquire relevant information, increase their absorptive capacity and manage waste quality.

Figure 5 graphically presents the above discussion. Figure 5 shows that misaligned SI results in a low acquiring capability, a low absorptive capacity and a low capability to manage waste quality, whereas aligned SI increases the supplier's acquiring capability, their absorptive capacity and also their ability to align the waste quality with production requirements. Moreover, Figure 5 also shows that the buyer can proactively align their knowledge base by involving different departments and individuals.

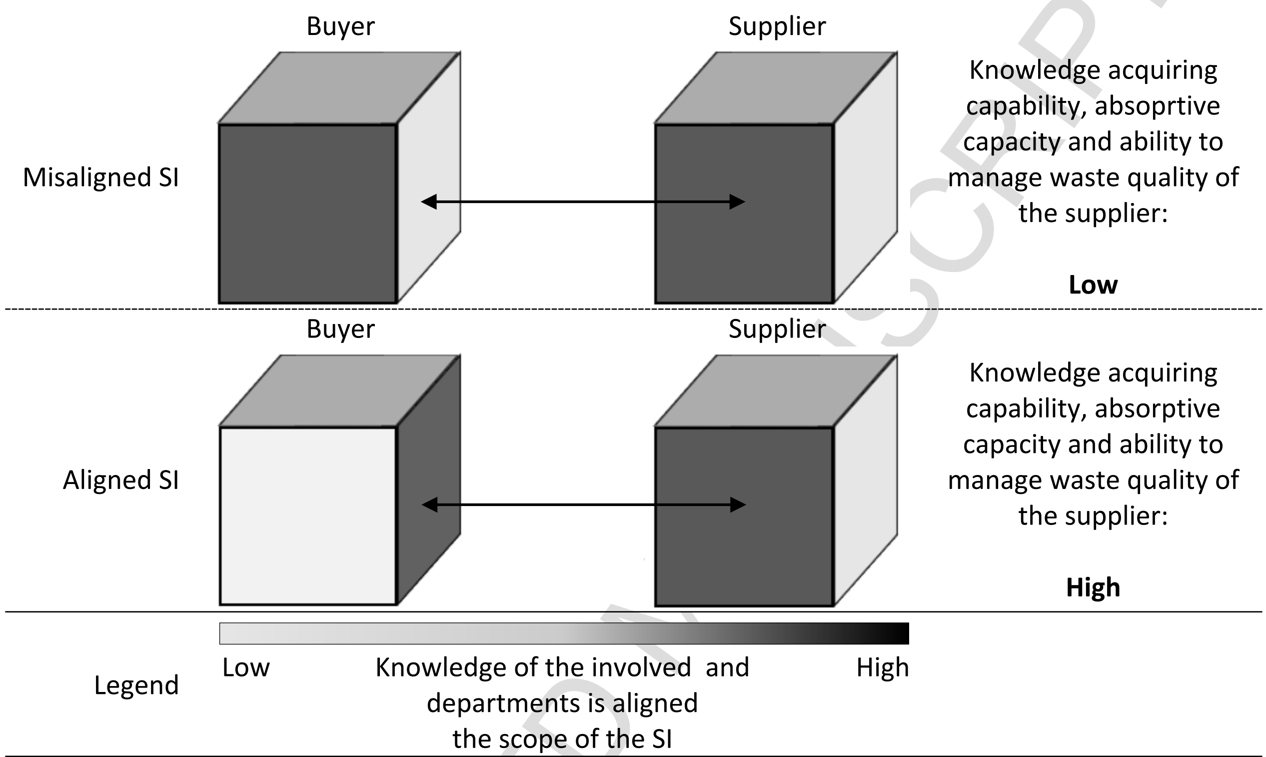

Fig. 5. The effect of misaligned and aligned SI in the context of high internal manufacturing complexity. The sides of the cubes represent the different departments and individuals in firms, the colors of the sides of the cubes represent whether the knowledge of the involved individuals and departments is aligned with the scope of the SI. The arrows represent the SI. When the parties involved in the SI do not have knowledge bases which are aligned with the SI, the SI becomes inefficient (unaligned SI). To improve the efficiency of the SI to manage waste quality in a context with high internal manufacturing complexity, the parties involved in the SI should align their knowledge bases with the scope of the SI (aligned SI).

Cema's shift from misaligned SI to aligned SI through involving different knowledge bases suggest that buyers can proactively align their knowledge base with the scope of the SI. Hence, the third proposition of this research is:

P3. Buyers can proactively align their knowledge base by involving individuals and departments with knowledge relevant to the SI to increase the absorptive capacity of the supplier.

This proposition contributes to the understanding of the construct of absorptive capacity and SI as it combines Lane and Lubatkin's (1998) dyadic view on absorptive capacity with insights from amongst others Galbraith (1973) who holds that firms can have multiple knowledge bases – e.g. logistics, operations (Swink and Schoenherr, 2014). Lane and Lubatkin's (1998) dyadic view on absorptive capacity holds that firms have a singular knowledge base (e.g. industry related). According to the dyadic view, when buyers and suppliers have the same knowledge base, their absorptive capacity will be higher and when they have different knowledge bases, their absorptive capacity will be lower. By combining this dyadic view with the insight that firms can have multiple knowledge bases (e.g. logistics, operations), firms can proactively align their knowledge bases in order to increase their absorptive capacity. As such, the third proposition contributes to the current understanding of absorptive capacity and SI.

Conclusion

In this paper a longitudinal case study was conducted to explore the shift from misaligned to aligned SI in the context of industrial symbiosis in the cement industry by addressing the research question: *how and why does misaligned and aligned SI enable suppliers to manage waste quality in the context of high internal manufacturing complexity?* Our empirical data suggests that involving the right individuals in the SI is important for managing waste quality in industrial symbiosis in a context of high internal manufacturing complexity. It also shows how the construct of absorptive capacity guides the involvement of the right individuals based on knowledge base identification.

This study is among the first to focus on optimizing the operational and supply chain processes of industrial symbiosis. The cost savings of Cema highlight the importance of linking operational and supply chain processes as a means of making symbiotic relationships economically viable. Moreover, the optimization of the symbiotic operational and supply chain processes enables firms to extend the scope and scale of industrial symbiosis beyond 'low hanging fruits'. Since the process industry is often characterized by high internal manufacturing complexity, the findings of this study apply to the majority of the industrial symbiosis activities and, hereby, advances the field of cleaner production. In addition, the findings related to the concept of absorptive capacity are valuable for virtually all SI practices, thereby going beyond the context of industrial symbiosis.

Second, this study contributes to literature in several ways. The current study is in line with the development of the academic field of industrial symbiosis to study the concept from a supply chain and operations management perspective. This development towards an operational perspective is necessary to advance the increasingly mature field of industrial symbiosis: firms need new knowledge to use waste and byproducts not only as resources, but also as high-quality resources. This study contributes to this field by being among the first to study SI – a main concept in the field of supply chain management – in the context of industrial symbiosis. Furthermore, this study has implications for the academic understanding of the construct of absorptive capacity. Literature on absorptive capacity argues that absorptive capacity depends on the relative relationship between the knowledge bases of the involved firms. This paper's findings build upon this by suggesting that firms can proactively involve and disengage knowledge bases from the SI to increase the absorptive capacity. As such, the findings emphasize the importance of the existence of multiple knowledge bases (e.g. logistics and operational knowledge) on the construct of absorptive capacity.

This research benefits from further research. First, aligned SI may also have disadvantages such as too much emphasis on aligning waste quality with production requirements due to the involvement of operations managers (rather than an overall cost emphasize) Furthermore, the inclusion of different mindsets in misaligned SI might lead to new insights and angles to a problem. The disadvantages of aligned SI benefit from further research. In addition, the relationship between aligned SI and other aspects of supply chain management requires further research: poor supplier relationships and power imbalances between buyers and suppliers may affect the effectiveness of aligned SI in managing waste and byproduct quality. Another important direction for future research is to explore other types of misaligned SI (this paper only considers quadrant C of figure 2). The other types of misaligned SI may require different solutions due to different challenges. Absorptive capacity might provide a useful theoretical lens for such research.

As a final reflection, this paper is not without limitations. The main limitation is the reliance on a single case. There is, therefore, a need for additional case studies in both similar and different settings to further explore the research question. Another major limitation of this study lies in the inductive nature based on the observations of a single case. The findings of this study, therefore, benefit from future research, which deductively tests the propositions on larger samples, for example through a survey study.

Nevertheless, despite the limitations, this paper has made an important contribution to both literature and practice by enhancing the understanding of SI performance in terms of how and why SI performance is conditioned by absorptive capacity and how firms can increase SI performance.

References

Baas, L., Boons, F., 2004. An industrial ecology project in practice: exploring the boundaries of decision-making levels in regional industrial systems. J. Clean. Prod. 12, 1073–1085.

Bansal, P., McKnight, B., 2009. Looking forward, pushing back and peering sideways: analyzing the sustainability of industrial symbiosis. J. Supply Chain Manag. 45, 26-37.

Behera, S. K., Kim, J. H., Lee, S. Y., Suh, S., Park, H. S., 2012. Evolution of "designed" industrial symbiosis networks in the Ulsan Eco-industrial Park: "research and development into business" as the enabling framework. J. Clean. Prod. 29, 103–112.

Bozarth, C.C., Warsing, D.P., Flynn, B.B., Flynn, E.J., 2009. The impact of supply chain complexity on manufacturing plant performance. J. Oper. Manag. 27, 78-93.

Campbell, D.J., 1988. Task complexity: a review and analysis. Acad. Manag. Rev. 13, 40-52.

Cohen, W.M., Levinthal, D.A., 1990, Absorptive capacity: a new perspective on learning and innovation. Adm. Sci. Q. 35, 128-152.

Costa, I., Ferrão, P., 2010. A case study of industrial symbiosis development using a middle-out approach. J. Clean. Prod. 18, 984–992.

Das, A., Narasimhan, R., Talluri, S., 2006. Supplier integration – finding an optimal configuration. J. Oper. Manag. 24, 563-582.

Duflou, J.R., Sutherland, J.W., Dornfeld, D., Herrmann, C., Jeswiet, J., Kara, S., Hauschild, M., Kellens, K., 2012. Towards energy and resource efficient manufacturing: a processes and systems approach. CIRP Ann. Manuf. Technol. 61, 587-609.

Eisenhardt, K.M., 1989. Building theories from case study research. Acad. Manag. Rev. 14, 532-550.

Eisenhardt, K.M., Graebner, M.E., 2007. Theory building from cases: opportunities and challenges. Acad. Manag. J. 50, 25-32.

Evans, S., Beneditti, M., Holdago, M., 2017. MEASTRI exchanges database. Library of industrial symbiosis case studies and linked exchanges.

Feyissa, T.T., Sharma, R.R.K., Lay, K.K., 2019. The impact of the core company's strategy on the dimensions of supply chain integration. Int. J. Logist. Manag. 30, 231-260.

Frohlich, M.T., Westbrook, R., 2001. Arcs of integration: an international study of supply chain strategies. J. Oper. Manag. 19, 185-200.

Galbraith, J.R., 1973. Designing Complex Organizations, Addison-Wesley, Reading, USA.

Gioia, D.A., Chittipeddi, K., 1991. Sensemaking and sensegiving in strategic change initiation. Strateg. Manag. J. 12, 433-448.

Hair, J.F., Black, W., Babin, B.J., Anderson, R.E., 2009. Multivariate Data Analysis: A Global Perspective, Prentice Hall, New Jersey.

Herczeg, G., Akkerman, R., Hauschild, M.Z., 2018. Supply chain collaboration in industrial symbiosis networks. J. Clean. Prod. 171, 1058-1067.

Huber, G.P., 1991. Organizational learning: the contributing processes and the literatures. Org. Sci. 2, 88-115.

Huo, B., Ye, Y., Zhao, X, Zhu, K., 2019. Supply chain integration: a taxonomy perspective. Int. J. Prod. Econ. 207, 236-246.

Jick, T.D., 1979. Mixing qualitative and quantitative methods: triangulation in action. Qual. Methodol. 24, 602-611.

King, P. L., 2009. Lean for the process industry. Dealing with complexity. Taylor & Francis, New York.

Kleindorfer, P.R., Singhal, K., van Wassenhove, L.N., 2005. Sustainable operations management. Prod. Oper. Manag. 14, 482-492.

Kähkönen, A.K., 2014. The influence of power position on the depth of collaboration. Supply Chain

Manag Int. J. 19, 17-30.

Lane, P.J., Koka, B.R., Pathak, S., 2006. The reification of absorptive capacity: a critical review and rejuvenation of the construct. Acad. Manag. Rev. 31, 833–863.

Lane, P.J., Lubatkin, M., 1998. Relative absorptive capacity and interorganizational learning. Strateg. Manag. J. 19, 461-477.

Masi, D., Kumar, V., Garza-Reyes, J.A., Godsell, J. 2018. Towards a more circular economy: exploring the awareness, practices, and barriers from a focal firm perspective. Prod. Plan. Control. 2018, 539-550.

Manuj, I., Sahin, F. 2011. A model of supply chain and supply chain decision-making complexity. Int. J. Phys. Distrib. Logist. Manag. 41, 511-549.

Meneghetti, A., Nardin, G., 2012. Enabling industrial symbiosis by a facilities management optimization approach. J. Clean. Prod. 35, 263–273.

Mirata, M., 2004. Experiences from early stages of a national industrial symbiosis programme in the UK: determinants and coordination challenges. J. Clean. Prod. 12, 967–983.

Nagati, H., Rebolledo, C., 2012. The role of relative absorptive capacity in improving suppliers' operational performance. Int. J. Manag. Rev. 32, 611–630.

Park, H., Chung, C.C., 2019. The role of subsidiary learning behavior and absorptive capacity in foreign subsidiary expansion. Int. Bus. Rev.

Pettigrew, A., 1990. Longitudinal field research on change: theory and practice. Org. Stud. 1, 267-291.

Pires, A., Martinho, G., Rodrigues, S., Gomes, M.I. 2019. Sustainable solid waste collection and management. Springer.

Prosman, E.J., 2018. Supply chain capabilities for industrial symbiosis in the process industry. Lessons from the cement industry. Aalborg University Press.

Prosman, E.J., Scholten, K., Power, D.M., 2016. Dealing with defaulting suppliers using behavioural based governance methods: an ageny theory perspective. Supply Chain Manag Int. J. 21, 499-511.

Prosman, E.J., Wæhrens, B.V., Liotta, G., 2017. Closing global material loops: initial insights into firm-level challenges. J. Ind. Ecol. 21, 641-650.

Qu, S.J., Zhou, Y.Y., Zhang, Y.L., Wahab, M.I.M., Zhang, G., Ye, Y.Y., 2019. Optimal strategy for a green supply chain considering shipping policy and default risk. Comput. Ind. Eng., 131, 172-186.

Rojo, A., Stevenson, M., Lloréns Montes, F.J., Perez-Arostegu, M.N., 2018. Supply chain flexibility in dynamic environments: the enabling role of operational absorptive capacity and organisational learning. Int. J. Oper. Prod. Manag. 38, 636-666.

Schoenherr, T., Swink, M., 2012. Revisiting the arcs of integration: cross-validations and extensions. J. Oper. Manag. 30, 99-115.

Setia, P., Patel, P.C., 2013. How information systems help create OM capabilities: consequents and antecedents of operational absorptive capacity. J. Oper. Manag. 31, 409-413.

Simon, H.A., 1991. Bounded rationality and organizational learning. Org. Sci. 2, 125-134.

Stuart, I., McCutcheon, D., Handfield, R., McLachlin, R., Samson, D., 2002. Effective case research in operations management: a process perspective. J. Oper. Manag. 20, 419-433.

Summerbell, D.L., Barlow, C.Y., Cullen, J.M., 2016. Potential reduction of carbon emissions by performance improvement: a cement industry case study. J. Clean. Prod. 135, 1327-1339.

Swink, M., Schoenherr, T., 2014. The effects of cross-functional integration on profitability, process efficiency, and asset productivity. J. Bus. Logist. 36, 69-87.

Turner, N., Aitken, J., Bozarth, C., 2018. A framework for understanding managerial responses to supply chain complexity. Int. J. Oper. Prod. Manag. 38, 1433-1466.

Van Donk, D. P., Van Dam, P., 1996. Structuring complexity in scheduling: a study in a food processing industry. Int. J. Oper.Prod. Manag. 16, 54–63.

Vanpoucke, E., Vereecke, A., Wetzels, M., 2014, Developing supplier integration capabilities for sustainable competitive advantage: a dynamic capabilities approach. J. Oper. Manag. 32, 446-461.

Voss, C., Tsikriktsis, N., Frohlich, M., 2002. Case study research in operations management. Int. J. Oper. Prod. Manag. 22, 195–219.

Williamson, O.E., 1982. The economics of organization: the transaction cost approach. Am. J. Sociol. 87, 548–577.

Wong, C.W.Y., Lai, K.H., Bernroider, E.W.N., 2015. The performance of contingencies of supply chain information integration: the roles of product and market complexity. Int. J. Prod. Econ. 165, 1–11.

Yenipazarli, A., 2019. Incentives for environmental research and development: consumer preferences, competitive pressure and emissions taxation. Eur. J. Oper. Res. 276, 757-769.

Yin, R., 2009. Case Study Research: Design and Methods. Sage Publications, London.Zahra, S.A., George, G., 2002. Absorptive capacity: a review, reconceptualization, and extension. Acad. Manag. J. 27, 185–203.

Zeng, H., Chen, X., Xiao, X, Zhou, Z., 2017. Institutional pressures, sustainable supply chain management, and circular economy capability: emperical evidence from Chinese eco-industrial park firms'. J. Clean. Prod. 155, 54-65.

Zhang, M., Zhao, X., Lyles, M.A., 2018. Effects of absorptive capacity, trust and information systems on product innovation. Int. J. Oper. Prod. Manag. 38, 493-512.

Zhao, X., Huo, B., Selen, W., Yeung, J.H.Y., 2011. The impact of internal integration and relationship commitment on external integration. J. Oper. Manag. 29, 17-32.

- Using poor waste quality lowers production efficiency in industrial symbiosis
- Waste quality parameters can be ambiguous and therefore hard to manage
- Buyers can help suppliers to manage waste quality through supplier integration
- Absorptive capacity explains the effectiveness of supplier integration
- Aligning waste quality with production requirements improves production efficiency