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Review

Implementing life cycle assessment in green supplier selection: A systematic review and conceptual model

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1. Introduction

While interest in sustainable supply chain management has risen considerably in recent years (Carter and Rogers, 2008; Seuring and Müller, 2008; Carter and Liane Easton, 2011; Dubey et al., 2017), companies continue to lack oversight of their environmental and

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social impacts – due in part to limitations in measuring and managing the sustainability performance of their supply chain (O'Rourke, 2014). As managing and evaluating suppliers is an essential part of meeting companies' environmental goals, purchasers are in a critical position to influence the size of the overall environmental footprint of their companies (Walton et al., 1998: 9). Thus, better sustainability measuring and the ability to translate this into useful information for decision-makers is needed to limit and prevent unsustainable practices (O'Rourke, 2014).

Despite the growing attention to the topic of green supplier selection (GSS), and the vast number of operations research infused decision models for GSS suggested in the literature (Igarashi et al., 2013), it is not obvious how purchasers can operationalize such models as part of their sustainable procurement strategies. A plethora of measures and policies have been developed over the years to control and eventually to prevent depletion of resources and pollution associated with global production of goods and services; most notably from end-of-pipe abatement technology, to the concept of cleaner production (Frondel et al., 2007). In this paper, we explore the use of Life Cycle Assessment (LCA) to inform sustainable decisions in supplier selection.

Since its inception in the early nineties, LCA has become an established and widely used tool to ascertain environmental impacts of goods and services (Finnveden et al., 2009). Through LCA, practitioners are able to measure the cumulative impacts associated with the flow of energy and material in production systems. This includes the environmental aspects and potential impacts from all stages of a product or services' life cycles; from extraction of raw materials to final disposal, including all intermediate stages (ISO 14044:2006). Thus, LCA can provide solid information on upstream and downstream activities, allowing organizations to better gauge the environmental pressures they exert onto their supply chain. What makes LCA attractive from a purchasing perspective, is that it may offer insight into how choosing a certain supplier can affect the overall environmental system performance (Kjaerheim, 2005). Through LCA, purchasers may uncover how changes in production methods or material choices at one point in the supply chain affect upstream and downstream activities elsewhere.

For suppliers, providing life cycle-based information is becoming part of meeting demands for environmental documentation of products, both in the public and private sector. There is a growing market for the development and use of LCA in supplier selection, in part driven by requirements from green public procurement (GPP) (Fet et al., 2011, 2014). In fact, LCA has already been encouraged as a tool for green decision-making in EU policy since the early 2000s (European Commission, 2003), with many EU/EEA member countries citing the use of LCA in developing GPP criteria (Evans et al., 2010). Yet, practical cases of LCA in purchasing decisions remain surprisingly sparse in the literature (Parikka-Alhola and Nissinen, 2012a; Cheng et al., 2018).

Discussions of LCA in a supplier selection setting seem primarily to belong to one of two strands of literature, each representing a certain perspective. First, there is the literature focusing on Supply Chain Management (SCM) and Operations Management (OM). This strand of literature also includes purchasing and procurement oriented journals. Essentially, the perspective taken in this literature is concerned with the organization and management of operations, both internally in organizations and in a wider supply chain and network. In this literature, LCA is cursorily discussed as a tool or underlying aspect for achieving green, environmental or sustainable supply chain management (Sarkis, 2012; Beske et al., 2014; Seuring, 2013; Seuring and Müller, 2008; Matos and Hall, 2007). The second strand of literature covers Cleaner Production, Environmental Sciences and Sustainability oriented journals. Fundamentally, the perspective taken in this literature is concerned with sustainability as a scientific concept. The contributions addressing LCA in a purchasing context largely deal with the viability and technical possibilities of the LCA method in purchasing decisions (e.g. Westkämper, 2000; Hochschorner and Finnveden, 2006; Tarantini et al., 2011; Nowack et al., 2012; Pelton and Smith, 2015) or with LCA as an aspect of life cycle management (LCM) in environmental supply chain practices (Brent and Visser, 2005; Chen, 2005; Handfield et al., 2005; Nawrocka et al., 2009). Additionally, the topic is to a lesser degree discussed in the context of informing policy and business.

As the phenomenon of LCA in supplier selection draws upon literature from both perspectives, a coherent analysis of these is necessary to provide a meaningful review of the field. Furthermore, given the importance of the decision-making role in sustainable supply chains (Wu and Pagell, 2011), the lack of explicit guidance for purchasers in utilizing available tools provide important research opportunities. An overview of GSS provided by Igarashi et al. (2013), found LCA to be an emerging topic within the field. More recently, a systematic review of missing concepts and future trends in GPP highlight applications of LCA as an important research gap in this literature (Cheng et al., 2018).

In this paper, we therefore present a comprehensive overview of LCA in supplier selection, providing a conceptual model for strategic LCA implementation in organizations. We see a clear need to assess and review the literature from the perspectives of both management and sustainability, in order to provide a novel contribution to the research on *how LCA can be operationalized as a tool for purchasers to carry out sustainable practices*. Because of the complexity and many facets of purchasing, we apply a framework for Green Supplier Selection (GSS) developed by Igarashi et al. (2013) to further delimit our research focus. Accordingly, we categorize and review the literature based on the four dimensions of GSS; specifically, how LCA is aligned with policy in supplier selection, how LCA-based tools can be implemented by purchasers, LCA in the supplier selection process, and finally how supply chain contexts affect the use of LCA. Applying this framework leads us to the following research questions:

RQ1 How can LCA-based methods help organizations align with local and national sustainability strategies?
RQ2 How is LCA implemented in purchasing?
RQ3 In which stages of the supplier selection process is LCA used, and which life-cycle stages are included in purchasing criteria?
RQ4 What is the role of purchasers in supply chain contexts, and what is the importance of LCA capabilities?

We answer these research questions by systematically gathering, classifying and analyzing all relevant papers found in the intersection between LCA and supplier selection. This has theoretical and practical implications. The first major contribution of this paper is the systematic literature review, which aims to advance the research on LCA implementation and contribute to an area of the supplier selection field that has not received much attention (Parikka-Alhola and Nissinen, 2012a; Cheng et al., 2018). Secondly, based on this research data, we construct a conceptual model for strategic LCA-implementation in supplier selection, which can be used by purchasers and procurement officers to help align purchasing strategy with sustainable policy goals in organizations.

The paper is organized as follows. Section 1 provides an overview of the problem and research questions. In Section 2 we present our research method and systematic review process, before presenting our results in Sections 3 and 4. First, we present a descriptive analysis of the sample, followed by a framework

analysis to structure the qualitative findings. In Section 5 we discuss the relevance of the research and present a conceptual model for LCA implementation in Green Supplier Selection. Finally, in Section 6 we conclude our contribution and provide opportunities for further research.

2. Research methodology

2.1. Systematic literature review

In this paper, we provide a broad and detailed account of the research found in the intersect between LCA and purchasing. Because this topic seems to be discussed from several perspectives and academic disciplines, we applied a systematic review approach to ensure a thorough coverage of the research field. Systematic literature reviews follow a specific review protocol and search strategy developed to meet the research questions (Kitchenham, 2004), and as opposed to narrative reviews, are characterized by the application of explicit procedures for replicability and avoiding research bias (Tranfield et al., 2003). A key element is therefore found in the documentation of the procedures, decisions and conclusions of the researchers (Bryman, 2015). Following this approach, we planned and conducted a preliminary review of the literature to better define the research questions and improving the literature search method. A first version of the paper was subject to peer review and presented at the 2016 EurOMA conference. In the following sections, we summarize in detail our research approach before presenting our findings in Sections 2 and 4.

2.2. Data collection and keywords

An academic data mining software, Publish or Perish (Harzing, 2007), was used trawl, aggregate and output all relevant results based on our input, including metadata metrics. The software utilizes the Google Scholar index database, which entails a few implications that first need to be addressed. Google Scholar is an academic search engine, indexing the contents of academic databases such as Elsevier and Scopus. Therefore, to check the inclusiveness of our approach, we confirmed that Google Scholar accesses and indexes all relevant journals from environmental sciences (e.g. Journal of Life Cycle Assessment, Environmental Science and Technology), cleaner production (i.e. Journal of Cleaner Production), Operations Management journals (e.g. Journal of Operations Management, Journal of Operations Research) and supply chain management journals (e.g. Journal of Purchasing and Supply Management). An overview of journals included in the search is given in Table 1. Additionally, we performed spot checks and manually confirmed that the program returned the same result as a regular search in Google Scholar.

There were some benefits and drawbacks of this approach. Most importantly, it allowed us to pinpoint relevant literature related to our research scope. While requiring careful preparation and a rigid review protocol, it eliminated in our case the need to conduct countless individual searches in each specific academic database before recording, consolidating and identifying duplicates in the material. Conversely, limitations of database search capacity during data mining and indexing may result in missing some sources that weren't already indexed properly by the search engine that otherwise would have been spotted when conducting separate searches. In a broader field of research, this could prove problematic if some papers systemically were to be excluded from search iterations because of indexing issues not captured by the search algorithms.

Keywords were developed over several iterations in order to narrow the scope of the review, with the intention of producing a sample with unique results. Based on the initial findings, we identified and included some key topics that needed to be addressed to answer the research questions; methods used by purchasers, the environmental sustainability dimension and lastly the supply chain context in which purchasers operate in. Each topic is defined by keywords that put together with keywords from the other topics forms a search string. For instance, the topic *environmental sustainability* consisted of three keywords; "environment", "green" and "sustainable". Incorporating all possible keywords related to these topics in the search would however result in an enormous amount of possible string permutations. Thus, we applied Boolean operators to conduct the search iterations more efficiently, and to decrease the occurrence of duplicates. The operator "AND" means that both words preceding and following the operator must be included. Accordingly, "OR" allows the inclusion of either word preceding or following the operator. Lastly, we avoided using so-called wildcards, where for instance using the keyword "purchas*" will include both "purchaser" and "purchasing". After several iterations, we found this approach to yield a search result more focused on the purchasing function specifically rather than purchasing in general. Using the appropriate syntax for Google Scholar, we arrived at the following search string: "LCA AND (purchasers OR procurers), green sustainability environmental".

Our search string thus provided a sample counting n = 997, with

Table 1
Distribution of journals and research areas (adopted from Cheng et al., 2018).

Category	Field/journal	# of articles	Years
A	Cleaner Production, Environmental Sciences and Sustainability	26	2001–2018
	Business Strategy and the Environment	2	2007–2010
	Ecological Economics	1	2008
	Economics and Policy of Energy and the Environment	1	2016
	Energy	1	2011
	Environment, Development and Sustainability	1	2016
	Environmental Management and Health	1	2001
	Environmental science & technology	2	2007–2016
	Greener Management International	1	2001
	International Journal of Environment and Sustainable Development	1	2010
	International Journal of Life Cycle Assessment	6	2004–2018
	International Journal of Sustainability in Higher Education	2	2011–2012
	Journal of Cleaner Production	5	2006–2018
	Journal of Industrial Ecology	1	2015
	Sustainability	1	2016
B	Operations Management, Procurement and Manufacturing	6	2005–2017
	International Journal of Construction Management	1	2012
	International Journal of Operations & Production Management	1	2017
	Journal of Public Procurement	1	2012
	Journal of Purchasing and Supply Management	2	2013
	Plastics, rubber and composites	1	2005
C	Policy, Legislation and Business	7	2005–2017
	British Food Journal	2	2005–2010
	European Procurement & Public Private Partnership Law Review	1	2013
	Food Policy	1	2016
	Regional and business studies	1	2012
	Society and Economy	1	2011
	WMU Journal of Maritime Affairs	1	2017

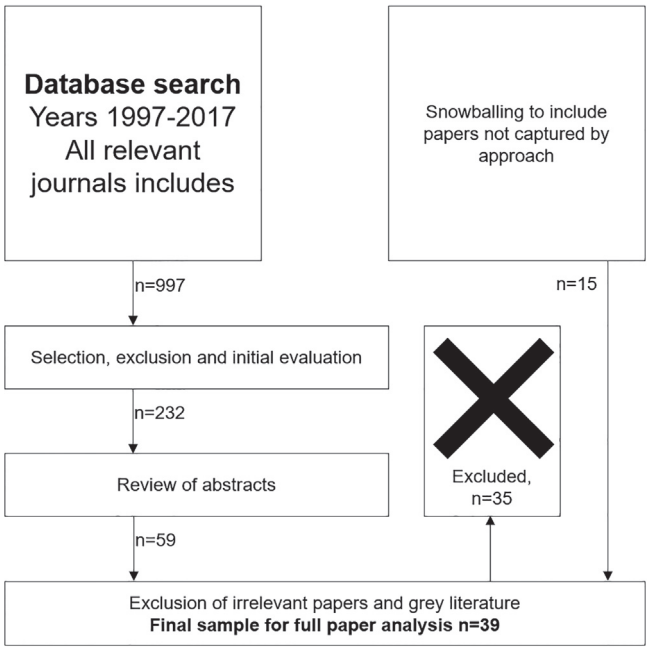

Fig. 1. Overview of data gathering and culling procedure. The total sample was N = 1012 unique hits.

very few duplicates. A few papers were manually discovered, as they were either not "read" properly by the database search method due to indexing errors or were thematically important without the right keywords to register as a hit within our search parameters. These were typically found as references used in papers from our main sample. These additional findings counted n = 15, resulting in a total initial sample of N = 1012 as shown in Fig. 1. These results were then exported to a spreadsheet for further analysis.

2.3. Sorting and exclusion process

The following exclusion criteria were used in the paper. First, we selected papers spanning only the last two decades (1997–2017).[1] LCA is a relatively new scientific method. The first impactful methodological handbook was published in 1992 (see Heijungs et al., 1992), and the first standardization of the method came in 1997 (ISO, 1997). Moreover, we excluded all results not in English or any of the Scandinavian languages. Due to a combination of the keywords and the inclusion of grey literature by Google Scholar, the sample contained a few technical reports, governmental documents or other non-academic papers, which were excluded. Additionally, we decided to not include book chapters, conference proceedings and theses. Then, remaining papers were culled by titles. If the title did not contain any of the keywords relating to the three topics, it was omitted. As a final precaution, we randomly picked some of the discarded results to verify that we did not omit any relevant papers. None were taken back into the final sample.

Finally, we reviewed the abstracts of the remaining sample. The abstracts were numerically scored, with a higher score signifying a highly relevant result dealing with LCA or other relevant tools used in a purchasing or procurement decision. Some papers were discussing the application of the method(s), but not specific enough towards purchasing or procurement. Such papers and other partially relevant results were graded 2. Obviously irrelevant results were discarded. Abstracts with a lower score were again reviewed and the full text was skimmed in order to establish its relevance. After culling the abstracts and including papers obtained through snowballing, we arrived at a final sample of n = 39 to be analyzed in full.

2.4. Category selection and framework analysis

To analyze our sample, we first classified the papers; according to year, location, research method, data type, if LCA was central and whether the paper discussed public and/or private purchasing (see Table 2). These categories were chosen to provide a comprehensive overview of the intersecting field of LCA and purchasing. The full descriptive analysis is presented in Section 2. In addition to these general categories, the preliminary literature search resulted in the identification of a need to better categorize and analyze the results against a theoretical framework. Consequently, we categorized and analyzed our findings by using a conceptual model for Green Supplier Selection (GSS) developed by Igarashi et al. (2013). We applied this model to structure the research questions and literature analysis, and how the dimensions of the model are applied is further detailed in Section 4.

3. Results and descriptive analysis

3.1. Distribution of publications over time

LCA as a method and green purchasing as a tool to reach more sustainable practices represent streams of literature that has been rapidly growing the last 15 years. However, while there has been a considerable increase in literature on green procurement practices (e.g. Igarashi et al., 2013; and more recently Cheng et al., 2018), we did not observe the same trajectory for literature in the intersect of LCA and procurement. As can be observed from Fig. 2, there is however a small but positive trend from 2010 and onwards, with the most papers in the distribution being published in 2016. In this context, it is therefore worth noting that use of LCA as a tool for green decision-making has been encouraged and included in EU policy since the early 2000s (European Commission, 2003). However, there are no discernible similarities in the topics of the papers published in the peak years.

3.2. Distribution of journals across research areas

We used a similar approach to Cheng et al. (2018) to structure and present the journal distribution as presented in Table 1. Papers found in the intersect of LCA and purchasing are chiefly discussed within the context of Cleaner Production, Environmental Sciences and Sustainability (Category A); from Operations Management, Procurement and Manufacturing (Category B); or within Policy, Legislation and Business (Category C). These categories are not mutually exclusive, and some papers could very well fit in all three. An interesting find is that LCA was only central in half of the sample, as observed from Table 2.

Two-thirds of the papers were found in Category A. We further observed that many of the papers in this category have been published in The International Journal of Life Cycle Assessment (Int J Life Cycle Assess) and in Journal of Cleaner Production (JoCP). Typical for papers published in these journals, and Category A in general, is that they seem to focus on method-centric research for environmental impact assessment, method development and decision-support.

[1] The search was conducted in several iterations throughout Q1-Q3 2017. Thus, we cannot with absolute confidence state that all relevant papers from 2017 were indeed included. Furthermore, two relevant and recent papers published after our initial data search were also included: Cerutti et al. (2018), Cheng et al. (2018).

Table 2
Results from the systematic literature review.

#	Author(s)	Year	Location	Type of paper/method	Type of data	LCA is central	Sector	Alignment	Tools	Process	Context
1	Zhu and Geng	2001	CN	Survey	Qualitative		Public				X
2	Curran	2001	US	Conceptual research	Qualitative	✓	General		x		
3	Matthews and Axelrod	2004	US	Case study	Qualitative	✓	Public				X
4	Bergström et al.	2005	SE	Survey	Qualitative		General	x			
5	Baitz et al.	2005	EU	Research note	Qualitative	✓	Public	x	x		
6	Byggeth and Hochschorner	2006	SE	Survey	Qualitative		General		x		
7	Hochschorner and Finnveden	2006	SE	Survey	Qualitative	✓	Public		x		X
8	Grankvist and Biel	2007	SE	Survey	Mixed	✓	General		x		X
9	Gloria et al.	2007	US	Survey	Mixed	✓	General		x		
10	Parikka-Alhola	2008	FI, SE	Document analysis	Mixed		Public	x			X
11	Varnäs et al.	2009	SE	Survey	Mixed		General		x		
12	Biel and Grankvist	2010	SE	Survey	Qualitative	✓	General	x	x	x	X
13	Solér et al.	2010	SE	Case study, survey	Qualitative		General	x		x	X
14	Young et al.	2010	UK	Case study	Qualitative		Public		x		
15	Fet et al.	2011	NO	Document analysis	Qualitative		Public	x		x	X
16	Tarantini et al.	2011	IT	Case study	Qualitative	✓	Public	x	x		
17	Thurston and Eckelman	2011	US	Case study	Quantitative	✓	General	x	x		
18	Parikka-Alhola and Nissinen	2012a	FI, SE	Case study	Mixed	✓	Public	x	x	x	X
19	Parikka-Alhola and Nissinen	2012b	FI	Case study	Mixed	✓	Public	x	x	x	X
20	Nowack et al.	2012	DE	Case study	Mixed	✓	Public		x		X
21	Diófasi and Valkó	2012	HU	Conceptual research	Mixed		Public	x			
22	Ingwersen et al.	2012	US	Case study	Quantitative	✓	General		x		
23	Bratt et al.	2013	SE	Case study	Qualitative		Public	x	x		X
24	Correia et al.	2013	UK	Research note	Qualitative		Public	x			X
25	Dragos and Neamtu	2013	RO	Conceptual research	Qualitative		Public		x		
26	Igarashi et al.	2013	NO	Review	Qualitative		Public	x		x	X
27	Igarashi et al.	2015	NO	Document analysis	Mixed		Public	x			
28	Pelton and Smith	2015	US	Case study	Quantitative	✓	General		x		
29	Testa et al.	2016	IT	Content analysis	Qualitative		Public	x			
30	Laurin et al.	2016	EU, NA	Research note	Qualitative	✓	General		x		
31	Cerutti et al.	2016	IT	Case study	Mixed	✓	Public	x	x		
32	Xu et al.	2016	CN	Case study	Quantitative	✓	Public		x		
33	Iraldo et al.	2016	IT	Survey	Qualitative		Public		x		
34	Pelton et al.	2016	US	Case study	Quantitative	✓	General		x		
35	Jungbluth et al.	2016	CH	Case study	Quantitative	✓	Private		x		
36	Luttenberger and Luttenberger	2017	HR	Conceptual framework	Qualitative		Public		x		
37	Pullman and Wikoff	2017	US	Research paper	Mixed	✓	General	x	x		
38	Cerutti et al.	2018	IT	Case study	Mixed	✓	Public	x	x		
39	Cheng et al.	2018	IT, CN	Review/Content analysis	Mixed		Public	x			

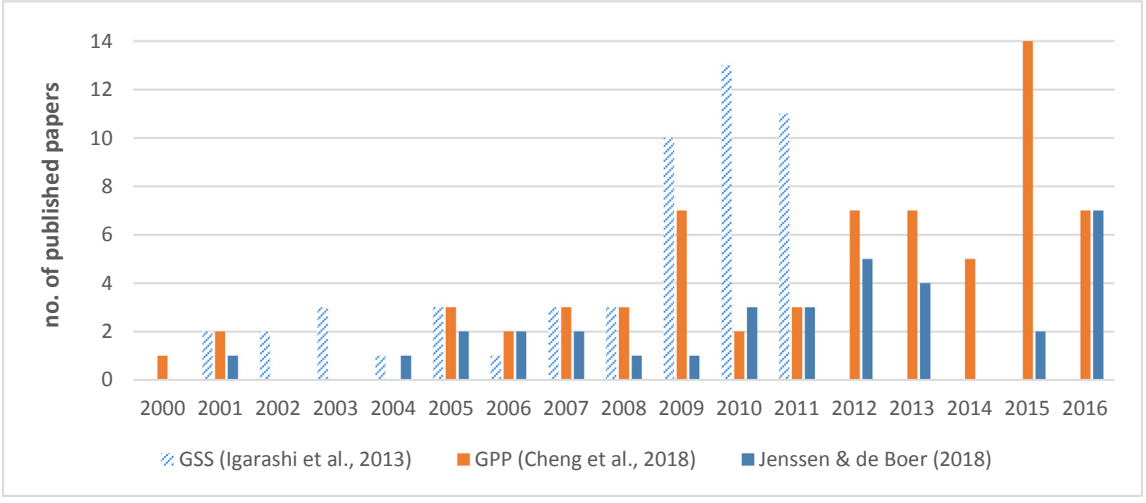

Fig. 2. Distribution of journal papers (2001–2016), compared with GSS (Igarashi et al., 2013) and GPP (Cheng et al., 2018) literature streams.

Papers in Category B were generally less concerned with the environmental impact of purchasing and procurement, with more emphasis on LCA as a part of strategy and its practical implementation as a decision tool. Journals specific to purchasing and public procurement is found here, such as Journal of Public Procurement (JOPP) and Journal of Purchasing and Supply Management (JPSM). Interestingly, papers describing practical implementations of LCA in a purchasing context were mostly found within this category.

Finally, the remaining papers of the sample were observed in

Category C. This is perhaps the broadest category we observed, ranging from policy to business. While the journals found in this category thematically sets them apart from categories A and B, topics such as policy alignment are heavily discussed in many of the papers in the sample. Furthermore, the papers found in the British Food Journal (BFJ) discussed in particular how LCA information informs and affect purchasers' propensities to choose more environmentally friendly products (Bergström et al., 2005; Biel and Grankvist, 2010). In that regard, these papers could thematically belong in both categories A and B.

4. Framework analysis

In this section, we will present a framework analysis of the sample. We review the papers using a conceptual model of GSS developed by Igarashi et al. (2013). This model synthesizes the results of a thorough review of general GSS literature and suggests that effective GSS requires a balanced consideration of four aspects: (i) the alignment of supplier selection with the overall environmental strategy or policy of the organization, (ii) the role and potential of decision support tools and models, (iii) the processual nature of GSS, providing several opportunities for including green criteria and (iv) the wider supply chain context in which GSS takes place, among other things covering the power balance between the buyer and the supplier. Following Igarashi's model, we categorize the papers by considering to what extent they address the four aspects, namely how the application of LCA in supplier selection is aligned with higher level policy, how LCA-based decision tools are applied in the supply chain, the positioning of LCA in terms of the various stages in the supplier selection process, and finally how the supply chain context affects the use of LCA. The GSS model was applied to all papers reviewed, and we allocated the papers to one or several of the categories (see Table 2). In Section 5 we provide a discussion of the results and establish a conceptual model for strategic LCA-implementation in purchasing and procurement decisions.

4.1. Strategic alignment

Although all 39 papers were reviewed using the GSS model, half of the sample described the alignment dimension in particular. Collectively, these papers directly and indirectly highlight how purchasers need to align their tools with purchasing strategy across organizational levels to bridge an implementation gap between policy and practice. Likewise, the literature stresses the importance of aligning policy decisions with informed analyses.

In the public sector, green procurement is encouraged through legislation, and it is the policy environment that largely determines engagement in GPP (Cheng et al., 2018). Several studies point out how purchasers align their activities with policy, legislation or mandate to structure environmental purchase decisions. Bergström et al. (2005) found that food purchasers in Sweden used corporate policy, ecolabels, and legislation to frame their environmental practice. A study by Biel and Grankvist (2010) showed that emphasizing company policy on environmental issues can help purchasers choose environmentally friendly alternatives, while Bratt et al. (2013) highlight the need to align criteria development with strategic outlooks in order to support GPP measures.

Successful implementation of environmental policies depends on the right tools being aligned with the right policy level (Testa et al., 2016). Several papers discuss how policy implementation varies between different levels of engagement. These policy levels are described as decisions being taken at the geographic governmental levels (e.g. Testa et al., 2016; Bergström et al., 2005); organizational, company and corporate levels (e.g. Bergström et al., 2005; Parikka-Alhola and Nissinen, 2012a); and higher, top-level decisions (Baitz et al., 2005; Nowack et al., 2012; Laurin et al., 2016). Depending on the policy level, the approach to implement and achieve GSS will therefore vary (Byggeth and Hochschorner, 2006).

Diófási and Valkó (2012) emphasize how high-level commitments and targets do not guarantee successful implementation at the purchasing level. As policies are translated into action, they may become weaker by the time they reach the purchaser, and a low level of understanding of green concepts can create a conflict between policy and practice. An analysis of the Norwegian public tender database by Igarashi et al. (2015) revealed that there seems to be a tension between policy-makers and practitioners concerning development and weighting of environmental award criteria presented to suppliers. Case studies on LCA-based criteria use in Finnish and Swedish public procurements, shows that ambiguity in the EC public procurement directives makes it difficult for purchasers to establish the full extent of environmental requirements (Parikka-Alhola and Nissinen, 2012a, 2012b).

The literature is also concerned with the effectiveness of environmental policy decisions, and how to use LCA tools to inform policymakers. Cerutti et al. (2016) used LCA to assess the performance of three food policy scenarios in the city of Turin. Their case study demonstrates how the application of specific environmental indicators can be used to measure the performance of environmental decisions. Accordingly, they find that using LCA to measure impacts of alternatives allows authorities to draw conclusions to improve, and correctly plan sustainability policies. Baitz et al. (2005) come to a similar conclusion. They explore the feasibility of using LCA to provide holistic decision-aid and integrate important facts in policy development. Using EC policy development for the PVC industry as a backdrop, they find that early-stage involvement of LCA is highly suitable to provide "fact-based sustainable decisions" in Green Public Procurement (Baitz et al., 2005: 98).

Several papers discuss the alignment of capabilities across the buyer-supplier relationship, and between actors at different policy levels. Fet et al. (2011) find that successfully adopting and using green criteria hinges on the inclusion of the supplier side. Buyers and suppliers are not necessarily aligned when it comes to environmental performance, thus asking suppliers for the right information is crucial for successful GPP. The knowledge and expertise of organizations are also discussed, and studies examining public tenders saw tendencies where the more complex tenders generally were issued by more experienced organizations (Testa et al., 2016). A few papers maintain that the capabilities required to support fact-based sustainable decisions necessitate early development at a top-level (Baitz et al., 2005; Hochschorner and Finnveden, 2006). Fet et al. (2011) find that effective GPP depends on knowledge and expertise that extends far beyond the supplier selection process. There are often instances where purchasers lack the capabilities to assess suppliers' environmental performance, or where the items purchased are too low in value to warrant expensive analysis. In these cases, criteria development efforts have to be developed outside of the purchase decision. Accordingly, several authors suggest escalating complex criteria past the purchasing level to expert practitioners (Baitz et al., 2005; Parikka-Alhola, 2008; Nowack et al., 2012).

4.2. Applications in the supply chain supporting decision-making

Empirical descriptions of LCA used in purchasing and procurement are limited (Hochschorner and Finnveden, 2006), and the topic is sparsely discussed in the literature (Parikka-Alhola and Nissinen, 2012a). Accordingly, Varnäs et al. (2009) found that the

use of environmental impact tools (e.g. LCA) in procurement could be further explored in future studies. Moreover, according to a recent literature review on missing concepts and future trends in GPP, the application of LCA in purchasing is still an important research gap (Cheng et al., 2018). In this review, we therefore strive to identify relevant papers discussing LCA in this context specifically. We also include additional papers examining the use of similar or vicinal assessment tools used in purchasing and procurement.

We identified examples of several studies where LCA was specifically discussed in a purchasing decision context; in food or food service procurement (Grankvist and Biel, 2007; Biel and Grankvist, 2010; Cerutti et al., 2016, 2018; Jungbluth et al., 2016; Pullman and Wikoff, 2017); construction and buildings (Tarantini et al., 2011; Parikka-Alhola and Nissinen, 2012b); transportation (Parikka-Alhola and Nissinen, 2012a); contracts for fuel and indoor lighting (Bratt et al., 2013). In two Swedish case studies, experiments with food purchasers showed that the way LCA information was presented to decision-makers had an effect on purchasers' preference of products (Grankvist and Biel, 2007; Biel and Grankvist, 2010). Cerutti et al. (2016, 2018) aided public authorities with LCA to identify indicators and to measure the effect of green food procurement policies. While LCA was not directly used by purchasers, it proved essential in developing sustainable strategies for public procurement. Tarantini et al. (2011) present a case study in Italy, where the aim was to investigate if LCA methodology could be used to define environmental criteria for public building tender processes. The authors were able to align LCA results with the strategic aims of the EU national action plans to propose mitigation strategies and criteria for effective GPP. Parikka-Alhola and Nissinen (2012a) examined a procurement of goods transportation service in a Swedish municipality. They found that LCA was a good source of information on the environmental impacts of tenders and can be used to indicate where to focus efforts in the procurement process. However, small variances in the LCA results can skew or disturb weighting of award criteria, making LCA more suitable for experts than purchasers. In another study (Bratt et al., 2013), researchers shadowed two criteria development processes at a Swedish governmental expert body for GPP. LCA reports were among several tools used by the expert body, but none were able to capture overall sustainability hot spots (Bratt et al., 2013: 314).

In many papers where LCA implementation is discussed, barriers to operationalizing the method is a hot topic. Hochschorner and Finnveden (2006) maintain that LCA currently cannot be used for supplier selection because suppliers are not able to deliver the necessary data. Tarantini et al. (2011) conclude that there is some usefulness in using LCA methodology in highlighting building impacts. However, the methodology cannot be used to immediately arrive at specific GPP criteria, and it also depends on what we know about the status of the supplier market. According to Nowack et al. (2012), purchasers should not exclusively base their decisions on current LCA methods, because of various methodological faults. Furthermore, the information is far too complex to be used as a basis for tender documents. Thus, with the limited time and resources a procurer has, information regarding the environmental aspects of a purchase must be condensed. Moreover, while identifying criteria with LCA is one thing, evaluating them is another. Data, time, and cost constraints limit the efficiency of LCA-based tools in the procurement context (Pelton and Smith, 2015).

Accordingly, the applicability of the method in purchasing and procurement has remained topical in the LCA literature. A major difficulty for successful GPP is a lack of information (Byggeth and Hochschorner, 2006), and several papers in our sample discuss how purchasers can use LCA-based environmental information (e.g. Bergström et al., 2005; Biel and Grankvist, 2010) to qualify and evaluate suppliers (Fet et al., 2011). Curran (2001) presented an early LCA-based framework to facilitate a simpler way for procurement officials and vendors to include environmental preferability in the procurement process. Baitz et al. (2005) discussed pathways and traps towards life-cycle based decision-support. The authors note that LCA can provide solid information for decision-makers, but stress that not all aspects of the life cycle must be analyzed with the same degree of detail. Different stakeholders can disagree on what should be considered in an analysis, and experience is needed to discern where in the life cycle to focus efforts. Likewise, Pullman and Wikoff (2017) used a simplified LCA approach to assess and evaluate the carbon footprint of stakeholder-driven food policies in an institutional setting. They found that buy local-strategies preferred by stakeholders came out worse than strategies focusing on reducing food waste.

In an effort to meet some of the limitations of the method, several papers present extended LCA methodologies. Where LCA can be used to derive indicators for environmental performance, it cannot provide a preference for one alternative over the other. This also includes trade-offs, such as assigning weights to impact categories that affect the environment in different ways. In a recent LCA capacity roadmap (Laurin et al., 2016), LCA experts outline the inability of the method to provide decision-makers with a clear environmental preference. Accordingly, several authors suggest using various multiple-criteria decision analysis (MCDA) methods to handle trade-offs and weigh indicators derived from LCA (e.g. Gloria et al., 2007; Nowack et al., 2012; Laurin et al., 2016; Xu et al., 2016). On the issue of high costs associated with LCA, two case studies sought to reduce the transaction costs of sustainable procurement by screening supply chains for hot spots (Pelton et al., 2016; Pelton and Smith, 2015). The studies combined conventional LCA with environmentally extended input-output (EEIO) approaches, where economic information is used to estimate environmental impacts associated with consumption. Using this method, the authors were able to provide opportunities for environmental impact reduction across a procurement portfolio (Pelton et al., 2016). A similar approach (EIO-LCA) was taken to showcase how coupling university expenditures with environmental information could inform procurement policy (Thurston and Eckelman, 2011; Ingwersen et al., 2012). Moreover, as the EC recognizes the use of Life Cycle Costing (LCC) as a tool for GPP (e.g. Dragos and Neamtu, 2013), researchers have attempted to include environmental externalities as a cost input to the LCC approach (Nucci et al., 2016; Luttenberger and Luttenberger, 2017).

Finally, the frequency of LCA use in purchasing and procurement is also discussed in the literature. Byggeth and Hochschorner (2006) analyzed Ecodesign tools supporting decision-makers and found only 8 out of 15 had a life-cycle perspective. Varnäs et al. (2009) surveyed the use of tools, such as LCA, in green construction contract procurement in Sweden. They found that LCA was mentioned in cases where project-specific requirements were applied. In a content analysis of public tender documents, Testa et al. (2016) observed a limited use of LCA in Italian construction tenders. Interestingly, the authors found that criteria where LCA had been referred to correlated positively with the greenness of tenders.

4.3. Process

An important dimension of GSS is *process*. Igarashi et al. (2013) argue that green purchasing and procurement should concern all stages of the supplier selection process; from early criteria formulation and qualifying suppliers, to award stage and contracting. Achieving GSS, therefore, necessitates a deliberate design of the selection process, wherein needs and possibilities are considered

for each stage, and for the entirety of the process. In this review, we aimed to explore how tools such as LCA are being used throughout the supplier selection process; to further understand how purchasers and procurement professionals use LCA, and how it relates to the sustainable supplier selection.

A few papers explore the use of green criteria throughout the supplier selection process. Igarashi et al. (2015) analyzed public tender documents for 41 ICT purchases in Norway. They found environmental requirements or criteria were used in 78% of the tender processes, with the highest frequency of criteria found at the specification stage. Environmental award criteria were also used in many projects. Although the authors identified the use of criteria that could in part be based on LCA (such as ecolabels), there were no records of LCA-specific criteria (like Environmental Product Declarations) being put to use in any of the tendering stages. This supports the results of an earlier analysis of 31 calls for tenders on furniture in Finland and Sweden (Parikka-Alhola, 2008), where none were found to use LCA-based EPDs as criteria. More recently, Testa et al. (2016) conducted a similar study of 164 public tenders in Italy, using the EU GPP Toolkit as a reference for green criteria. Their results showed that green requirements most often were included within technical specifications and within award criteria. This study also distinguished between green criteria that only met compliance (light green), to comprehensive (hard green) criteria; subsequently, these were much less used. Finally, Parikka-Alhola and Nissinen (2012a) and Parikka-Alhola and Nissinen (2012b) presented cases from public procurement where LCA as a method to formulate and evaluate award criteria was discussed.

One of the features of LCA is its ability to highlight the potential environmental impacts of products and services over their entire life-cycle. In a purchasing and procurement setting, this is helpful to establish where to focus efforts to increase sustainability performance. Within European public procurement frameworks, the EU has opened up for relating award criteria to any particular life-cycle stage (Luttenberger and Luttenberger, 2017); such as production, use-phase and so forth. In a large case study on public food procurement in Italy (Cerutti et al., 2016, 2018) the authors use LCA methods to assess food policies. They show that successful environmental policies and the implementation of these need to take into account which part of the procurement process or supply chain the policy is supposed to have an effect on. Furthermore, they argue that LCA is a prerequisite for sustainable public procurement policies, and propose simplified LCA-methods to be used for call for tenders. Finally, Luttenberger and Luttenberger (2017) highlight potential conflicts of interest in public procurement that can arise when different organizations are responsible for different life-cycle stages of the purchased products.

4.4. Context

The wider organizational and inter-organizational *context* in which GSS takes place is important in several ways (Igarashi et al., 2013). This dimension of the model emphasizes the relationship between buyers and suppliers, and how they communicate and understand each other's needs to successfully pass environmental requirements throughout the supply chain. Igarashi et al. (2013) highlight several potential barriers to GSS in the context dimension; e.g., power imbalances, suppliers not understanding or accepting the use of green criteria and suppliers withholding information. Furthermore, a main topic of the sampled literature is that implementing LCA in purchasing decisions is difficult (e.g. Hochschorner and Finnveden, 2006; Tarantini et al., 2011; Nowack et al., 2012; Pelton and Smith, 2015). Moreover, we see that the capabilities necessary for LCA implementation in purchasing can depend on capabilities within the organization, but in most cases these exist outside of the purchasing function (e.g. Fet et al., 2011). Thus, in this review, we find the *context* dimension to be important in two main ways. First, to explore the roles of purchasers in a supply chain context; secondly, whether the context of the purchase decision (i.e., organization, size, industry sector, public or private procurement and so forth) gives any indication on the capabilities required for LCA implementation.

Zhu and Geng (2001) note that successful implementation of green purchasing largely depends on the organization of the purchasing function. Fet et al. (2011) arrived at a similar finding, noting that the knowledge and expertise of organizations are increasingly important and that their success depends on the larger purchasing organization extending far beyond the purchasing department and supplier selection process. Through a case study on food purchasers in Sweden (Bergström et al., 2005), show that the purchasers aligned environmental considerations with company policy, but seldom in accordance with scientific methods. According to Igarashi et al. (2015: 444), one can expect purchasers to simplify decision-making processes when faced with additional cognitive demands (such as environmental criteria) – unless they are provided with additional resources to handle this increased complexity. Correia et al. (2013: 60) exemplify issues of so-called "wicked problems", where procurers have to deal with trade-offs between complex organizational or political priorities. Walker and Brammer (2009, in Correia et al., 2013) give an example of how UK public purchases chose to prioritize local agendas over a national sustainable purchasing focus. Thus, several studies give examples of external panels of experts being used to derive consensus-driven criteria or weighing of criteria based on LCA (Gloria et al., 2007; Parikka-Alhola, 2008; Bratt et al., 2013). A contrasting case is presented by Matthews and Axelrod (2004), where public buyers educated suppliers on how to get environmental information about their products.

Several of the papers in our review discuss LCA capabilities and the role of purchasers. An analysis showing the inclusion of green criteria in Italian public tenders (Testa et al., 2016) sheds light on the difficulties procurers are experiencing in implementing GPP practices. In a study on a university's supply chain impacts, Young et al. (2010) found that purchasers were unable to use Greenhouse Gas accounting tools to reduce emissions. Furthermore, they propose that universities can draw on specific subject expertise within the organization, such as academics, to aid purchasers. Parikka-Alhola and Nissinen (2012b) highlight how purchasers need to understand the LCA method to be able to formulate successful award criteria while still keeping within the EU legal framework. In another paper, the authors discourage purchasers from using LCA, reserving the method for expert practitioners (Parikka-Alhola and Nissinen, 2012a). This sentiment is also shared by Diófási and Valkó (2012), who argues that because purchasers often are jurists rather than experts in technical fields and science, they have major difficulties developing procurement criteria. Furthermore, this can be improved through strong cooperation between purchasers and experts. We found several instances of experts or professionals assisting purchasers in the literature; Zhu and Geng (2001) described purchasers inviting experts to integrate environmental issues to requirements, Cerutti et al. (2016) and Cerutti et al. (2018) aided the city of Turin in assessing food policies, Xu et al. (2016) gives an example of governmental purchasing using experts to develop consent on environmental indicators.

Finally, how purchasers use or are influenced by environmental information given by suppliers is also a topic in the literature. Solér et al. (2010: 19) suggest that the distance between supply chain member and the end-consumer, in terms of supply chain stages, is important for how environmental information is perceived and

used by purchasers. Case studies targeting food purchasers in Sweden saw that the way in which environmental information was presented influenced the purchasers' decision preferences. When raw LCA-information was supplied together with a labelling system indicating better or worse performance, the purchasers tended to choose more environmentally friendly than without the label (Grankvist and Biel, 2007). How purchasers were mentally "activated", e.g. through company environmental policy, also had an effect on preference for environmentally friendlier products (Biel and Grankvist, 2010: 257). Finally, according to leading expert practitioners, LCA experts should therefore also make an effort to better understand decision making science, as stakeholders "(…) such as procurers, (…) will respond differently to the same kind of LCA results (or information)" (Laurin et al., 2016: 444).

5. Discussion and conceptual model development

Based on the framework analysis presented in the previous section, four key findings emerge, which we shall discuss in more detail in this chapter. These are illustrated in Fig. 3. First, successful implementation of LCA in supplier selection seems to hinge on its alignment with the strategy, aims and goals of organizations. Secondly, there is a complexity gradient of the method that aligns with the ambitions, the capacity and capabilities of purchasers. Thirdly, the capabilities required for applying LCA varies depending on where in the purchasing process the tool is utilized, and the weight given to the tool in final decisions. Fourthly, unless the purchasing organization is equipped with the necessary capabilities and resources, LCA-based criteria are best developed at a higher implementation level to better align decisions with environmental goals and commitments. Combining these findings, we discuss the required alignment between the level of implementation and organizations' capabilities in order to assess the feasibility of LCA in different purchasing contexts. Finally, building on the discussion, we propose a conceptual model for strategic LCA-implementation in purchasing (Fig. 4).

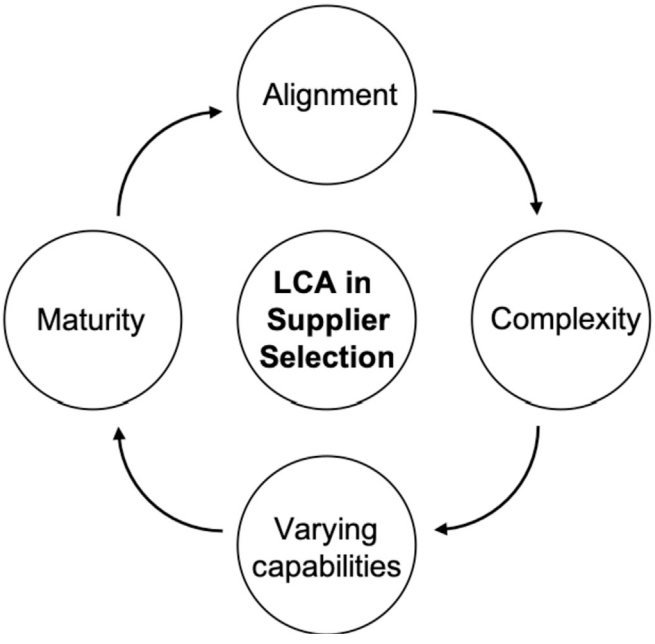

Fig. 3. Four key findings when discussing application of LCA in supplier selection processes.

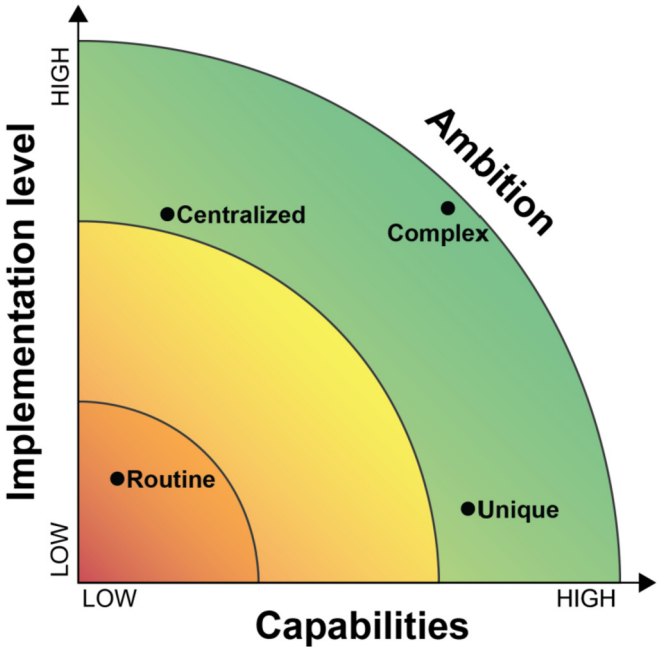

Fig. 4. Conceptual model for strategic LCA-implementation in purchasing and procurement. The implementation level and capability factors together form a complexity gradient (ambition) in which LCA implementation in supplier selection can be plotted and categorized.

5.1. Four key findings

First, an interesting theme that emerged from our literature review, was how LCA informs policy makers and organizational strategy. Green strategies are developed and executed across many levels, from top-level policy decisions, intraregional environmental strategies to municipal procurements. While LCA can inform decision makers across all levels, the way in which it best can be utilized differs (Baitz et al., 2005; Cerutti et al., 2016; Jungbluth et al., 2016; Parikka-Alhola and Nissinen, 2012a). While LCA was shown to be applicable throughout all policy levels, all cases found in the literature displayed the inclusion of external LCA experts to aid decision makers. It is also apparent from the literature that while LCA can be used in a variety of settings, it cannot be used in the same way in all contexts. The various use-cases further showed that the tool requires specific, contextual knowledge and capabilities. In other words, how LCA is used to discuss sustainability regulations for materials or industry differs from how it is used when purchasers need highly specific environmental information to decide between alternatives. Implementation of LCA in the context of purchasing therefore seems most successful when aligned with the strategy, aims and goals of organizations.

Secondly, the literature shows there are several ways purchasers can apply LCA. Papers not directly concerned with LCA as a method, generally tend to positively present LCA as an opportunity for decisionmakers to include environmental concerns. Suppliers may use it to provide documentation on their environmental performance, or LCA may be used to develop requirements and criteria to guide green supplier selection. On the other hand, papers authored by LCA practitioners voice a more critical position and emphasize limitations of using the method as-is. The method requires substantial resources in terms of time, money and competence. Thus, simplifications are needed if LCA is to be made available to the broad population of decisionmakers, without compromising the integrity of the method and the reliability of its results. Taken

together, the extant literature indicates a complexity gradient of the method that aligns with the ambitions, the capacity and capabilities of the purchasers in a given supplier selection process. Thus, for routine or low-value procurements, purchasers can utilize environmental declarations or eco-labels from suppliers together with guidance documents, where full LCAs can be saved for especially complex or unique procurements with sufficient resources. We return to this point in section 5.2.

Thirdly, LCA-based criteria seem to be mostly applied either at the specification stage or at the end of the supplier selection process as award criteria. Moreover, the LCA related criteria identified in the literature were ecolabel requirements used to obtain environmental information from suppliers (Igarashi et al., 2015; Testa et al., 2016). Given that the proper competence to make use of the information is at hand, purchasers can apply such criteria in the initial stages of a tender process to screen suppliers and tenders based on their environmental performance. In this way, they can specify an environmental performance threshold for bidders, or assign specific weights to the environmental performance of potential suppliers. In these situations, the need for purchasers themselves to perform LCAs to develop criteria is shifted toward suppliers. It still, however, requires the buyer to be capable of defining specific enough requirements and understanding the information provided by suppliers. Furthermore, LCA can be used in award criteria (Parikka-Alhola and Nissinen, 2012a, 2012b). However, small variations in the assumptions and environmental impact methodology may skew the final weighting. For public buyers, careful analysis is therefore necessary to ensure a transparent process. The capabilities required for applying LCA increase as the position of application gets closer to the final awarding of the contract (Igarashi et al., 2013). Also, purchasers must communicate to suppliers which life-cycle stages to focus on with a view to reducing impacts and complying with environmental strategies (Pelton and Smith, 2015; Pelton et al., 2016; Jungbluth et al., 2016). Receiving less attention in the literature we reviewed was how LCA can be used to develop general environmental criteria for certain categories of products made available to purchasers (e.g. European Commision, 2009; Magnadóttir et al., 2017; Dalhammar and Leire, 2012; Dalhammer, 2017). In these instances, LCA experts identify areas of special interest for GPP in meeting sustainable commitments.

Fourthly, understanding the supply chain context, and in particular the buyer-supplier relationship in which supplier selection takes place, is important when considering LCA as part of GSS. Purchasing organizations must be able, to the best of their abilities, to define specifications and requirements that enable them to meet environmental responsibilities. At the same time, suppliers need to provide accurate and reliable information to be able to be considered and further to compete on environmental aspects. In complex decisions, clear and relevant information plays a crucial role in reducing uncertainty (Citroen, 2011; Duncan, 1972). Purchasers tend to put more weight toward environmental performance if the information is structured in such as a way that it gives more meaning to the purchaser (Grankvist and Biel, 2007). Purchasers may also respond differently to the same LCA results or information (Laurin et al., 2016). We believe this illustrates the importance of purchasers clearly communicating their roles, their intentions and their needs to suppliers. It also requires purchasers to be aware of the types of environmental information that can be requested from suppliers and how to incorporate this in their decision processes. Furthermore, even when provided with accurate information, purchasers enact on this information based on their experience and competencies. Hence, unless the purchasing organization is equipped with the necessary capabilities and resources, LCA-based criteria may preferably be developed at a higher implementation level to better align decisions with environmental goals and commitments. This approach is already gaining traction in EU and EEA public procurement, with a notable example found in the Norwegian Agency for Public Management and eGovernment (Difi, 2018). Here, expert groups together with the agency provide pre-made environmental and CSR requirements for specific products and services that can be stipulated in public procurement processes.

Finally, we argue that these four key findings, as illustrated in Fig. 3, can work as guiding considerations when discussing implementation of LCA in supplier selection processes. As it emerges from the literature, organizations' environmental performance is ostensibly **aligned** with their ability to identify and act on aspects relevant to the organizations' green ambitions. At the same time, it is likely that the ambitions, the capacity and capabilities of purchasers together affect the level of perceived **complexity** faced when including environmental criteria. Moreover, depending on where in the purchasing process LCA is implemented, and how its results are weighted in final decisions, the required **capability** level for successfully using LCA will **vary**. Ultimately, we find that unless purchasing organizations are well-equipped to handle the complexity from including LCA, development of LCA-based criteria should be elevated to a higher, more **mature** level of decision-making better equipped for aligning actions with environmental goals and commitments.

5.2. Conceptual model for LCA-implementation

Based on the key considerations identified in the previous section, we propose a conceptual model for strategic LCA-implementation in supplier selection processes (Fig. 3). We find the model to be important for researchers, purchasers and procurers in several ways.

Fundamentally, the model serves to enable early inclusion of environmental considerations, aiding to avoid increased complexity and unintended costs later in the procurement process. Following Haskins and Forsberg (2011), the quality of the decision making, and at which stage the decisions are taken can determine the success of a project. Our framework analysis suggests that alignment of purchasing processes with environmental targets first requires a realistic consideration of the complexity of the process and how these conditions best are met. As plans and targets are prone to shift throughout the purchasing process, sustainability assessment methods need to be introduced as early as possible for decision-makers to be able to assess and readjust accordingly. This is especially important for EU and EEA GPP, where purchasers by law are required to take life cycle-considerations into account (Council Directive (EC), 2014). For transportation procurements, for instance, it would be highly relevant to investigate where in the life cycle of vehicles environmentally criteria would have the most effect. According to a comparative environmental study of electric vehicles compared with conventional gas-powered cars (Hawkins et al., 2013), the former alternative generally impacts the environment less in its use phase (i.e. driving). If municipal or company environmental goals dictated a reduction of carbon emissions from transportation services, purchasers could use such information to inform and influence the tender process and relate criteria to the life-cycle aspects with the most potential for effect. As Handfield et al. (2002) point out, traditional supplier evaluation systems may be of limited usefulness when assessing products with life cycles extending well into the future. In such, early involvement of life cycle considerations may prevent costly and time-consuming changes later in the procurement process. Early involvement may also aid in keeping green considerations in the purchasing process in line with the organization's environmental policy.

Secondly, the model may assist purchasers in reducing

complexity and uncertainty related to the application of environmental criteria. Based on the framework analysis, we see that lack of capabilities along with complexity in decisions seems to be a major factor limiting LCA implementation in procurement. Thus, in this model, we identify factors that contribute to guide, or illustrate, in which purchasing contexts LCA is relevant and at what level of implementation it can be used. The conceptual model is illustrated in Fig. 4, while examples of implementation are given in Table 3.

The main assumption in the conceptual model is that strategic LCA-implementation in purchasing and procurement needs to consider the alignment between factors "implementation level" and "capabilities". Given on the y-axis, we define the *implementation level* factor to include the various organizational levels and contexts in which we find purchasing and procurement. It includes high-level policy driven ambitions of carbon reduction, down to low-level, minimal requirement thresholds to satisfy legal requirements.

Accordingly, given on the x-axis, the *capabilities* factor is defined as the knowledge and experience present in the organization, in purchasers and in suppliers pertaining to the inclusion of environmental considerations in decisions. This includes knowledge of where in the purchasing process these criteria should be stressed, and subsequently where in the life cycle of products and services the purchaser wants to improve or influence. This includes knowing how to align the process with policy goals. Identifying the capability level of the purchasing organization may help decision makers follow through with purchasers when they are aligned with the ambitions of the organizations. This may be especially beneficial in situations where low-capability organizations inadvertently set more ambitious goals than they are capable of following through.

Finally, we propose *ambition* as a gradient representation of the relationship between the two factors. From the framework analysis we find that higher ambitions in purchasing decisions places additional cognitive demands on purchasers, further increasing decision complexity. In such, ambitious environmental decisions are taken at higher implementation levels or by more capable purchasing organizations. Thus, complexity is in this model not a measurable aspect, but rather the result of increased demand placed on decision makers. To provide an example, a procurement at a high implementation level with a high degree of organizational capabilities establishes a solid basis from which to set ambitious goals and expectations from suppliers. Conversely, to lower apparent complexity in green supplier selection, the level of implementation or need for capabilities must be lowered accordingly.

Thus, plotted between the axes, we find a multitude of purchasing contexts at various levels of ambition; including, but not limited to, centralized purchases, routine and frame agreements, big complex procurements, small or one-time procurements and so forth. In Table 3, we provide examples of situations of LCA implementation in purchasing decisions; centralized, complex, unique and routine. These four examples highlight how LCA is not a "one size fits all"-solution and how its use depends on the implementation level, the capabilities required and ambition of the procurement.

6. Concluding remarks and further research

6.1. Concluding remarks

This paper presents a novel contribution to the ongoing research streams on LCA in Green Public Procurement (GPP) and in Green Supplier Selection (GSS). Specifically, we considered the question how LCA can be operationalized as a tool for purchasers to carry out sustainable practices. Our comprehensive systematic review of the extant literature from the past two decades uncovered a moderately growing stream of publications, which, however, not seems to move into one specific direction. Still, our results support previous studies, showing that LCA-implementation still receives only limited attention in the supplier selection literature (Parikka-Alhola and Nissinen, 2012a; Cheng et al., 2018).

The subsequent framework analysis provided four key findings. Regarding our first research question (RQ1), the alignment of LCA with the strategy, aims and goals of organizations seem to be a major determinant for successful implementation of green criteria. LCA can, on the one hand, be used to inform policy and strategy decisions on a higher implementation level. On the other hand, LCA and LCA-based information may be used by purchasers to ensure that their efforts and activities align with policy goals and organizational mandates.

Regarding the second research question (RQ2), we find that LCAs role in the current purchasing practice mainly emerges as information passed on from suppliers through ecolabels and as a tool to provide decision aid in purchases with environmental significance. Exactly how purchasers can make full use of the method, however, still is an under-researched topic. The few case studies we found where LCA was applied show that the method may require substantial resources in terms of time, money and competence.

Addressing the final research questions (RQ3, RQ4), LCA seems most prevalent in the specification stage and as award criteria. Furthermore, we find that the capabilities required for applying LCA vary depending on where in the purchasing process the tool is utilized, and the weight given to the tool in final decisions. While these findings implicate that simplifications are needed if LCA is to be made available for purchasers in general, this simplification of the method may come at the expense of the reliability of its results and the interpretations thereof by users. Further research on decisions where LCA has been applied at various stages in the purchasing process, and with varying levels of LCA implementation is needed to gain a better understanding of this issue.

Concludingly, we find there is a complexity gradient of the

Table 3
Example typologies of LCA implementation in purchasing decisions.

Examples	Implementation level	Capabilities	Ambitions
Routine	Common, routine purchase, commodities (Pagell et al., 2010) handled by a single purchaser at organizational level.	Basic level of LCA sufficient.	Primarily assessing compliance to standards and higher level policies, sustaining impact.
Complex	Joint purchasing initiatives for transitional/strategic commodities or complex purchases of high economic/strategic value (Pagell et al., 2010).	Advanced LCA competence and substantial resources required.	Securing good environmental performance for large and complex purchases, facing high levels of uncertainty.
Centralized	Joint purchasing initiatives across units or at sector level (Schotanus and Telgen, 2007), transitional/strategic commodities (Pagell et al., 2010).	Moderate level of LCA competence sufficient, but large scale application requires substantial resources.	Achieving significant environmental impact by reaching many purchasing units at regional or national level, supporting policy.
Unique	Strategic, new task purchases, or transitional commodities (Pagell et al., 2010) handled by a cross-functional team in an organization.	Moderate to advanced level required, possibly involving specific external suppliers of competence.	Achieving significant environmental performance improvement in a specific, local project.

method that aligns with the ambitions, the capacity and capabilities of purchasers. Thus, while LCA can be used in a variety of settings, different contexts will require different resources. Time and cost restraints, capabilities and the environmental ambitions of the procurement may largely dictate the complexity of a purchase, thus also determining the scope of LCA-implementation. In such situations, a customized and enriched LCA analysis to meet diverse stakeholder concerns is far more suited to a one-off, lofty public procurement than for a purchaser looking to meet minimum requirements for a routine purchase. Unless the purchasing organization is equipped with the necessary capabilities and resources, LCA-based criteria are best developed at a higher implementation level to better align decisions with environmental goals and commitments.

Based on our results, we developed a conceptual model for strategic LCA-implementation in purchasing (Fig. 4). The model allows users to plot and assess the complexity of using LCA according to the implementation level and capabilities within the organization. Higher environmental ambitions lead to increased factors, further complicating the decision process. The implementation level and capability factors together form a complexity gradient in which LCA implementation in supplier selection can be plotted and categorized.

6.2. Implications, limitations and further research

Our findings and conceptual model illustrate the current state of LCA in supplier selection and how successful implementation is thought of to hinge on the alignment of implementation levels and capabilities. This has several implications.

6.2.1. Implications at the policy level

LCA has many facets and while its logic may be rather easily understood intuitively, application in practice is not straightforward. Policy should recognize the need for differentiation when it comes to the method. No type of implementation of the method is likely to fit all purchasing contexts. In line with a recognized need to build and strengthen public procurement competence in general, resources should be made available, at both central and selected regional levels, to develop and offer technical competence about LCA to purchasers.

6.2.2. Implications at the organizational, regional and sector level

One prevalent issue with LCA identified by practitioners and researchers is the lack of and access to knowledge and competence in using LCA and similar methods to derive and assess green criteria. Local management should secure a basic level of comprehension, creating access to knowledge about standards, as well as creating access to specific expertise at regional and national levels. Joint procurement initiatives may offer a context where resources can be bundled to give substantial attention to more specific LCA efforts that would otherwise be unavailable to single purchases.

6.2.3. Implications for professional communities and researchers

There is a clear need for interaction between communities of practice, creating more mutual understanding for each other's contexts to provide more effective exploitation of LCAs potential. Limitations and possibilities of the method that may be obvious for LCA practitioners may not be apparent for those managers putting plans to action. When the method is discussed, its intended use should be clarified, and it should be clear who develops the information, who uses it and which capabilities that are needed to implement LCA successfully. Because LCA in purchasing draws upon expertise from both management science and environmental disciplines, the phenomenon needs to be studied from a holistic viewpoint. Consequently, we find there is a great research opportunity in bridging the gap between the two perspectives. Regardless of current hurdles for purchasers to effectively implement LCA in supplier selection, LCA should still be regarded as an important tool to support green decision-making in purchasing.

6.2.4. Limitations of the study and concluding remarks

Our findings contribute to a growing stream of literature within GPP and GSS, supporting previous literature that calls for further case studies on LCA in supplier selection. This specific research field is still largely undefined, providing ample research opportunities in the intersect between LCA and supplier selection literature. Concomitantly, the extent of our research scope presents a limitation of the study. Because we highlight a very particular phenomenon in a rather broad field of literature, the inclusion and exclusion of keywords may affect the results of our literature review. By presenting a detailed approach to our systematic review, we aim to mitigate some of this uncertainty.

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