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Inclusion of sustainability aspects in product development – two industrial cases from Sweden

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Abstract

Knowledge on how to include sustainability aspects in product development has increased during the last 25 years. Research has contributed with literature reviews, case studies, and the development of supporting methods, frameworks and guidelines. Despite the large amount of knowledge generated on how to include sustainability aspects in product development, there are few studies that focus on describing how manufacturing companies, in real life, include sustainability aspects in their product development.

The aim of this paper is to describe how two manufacturing companies include sustainability aspects in their product development, make a comparison between them, and relate findings with prior studies. To fulfil the aim, a multiple case study at two large Swedish manufacturing companies was conducted. Data was collected through semi-structured interviews and by analyzing sustainability reports.

This paper provides two novel context-dependent descriptions of how large manufacturing companies include sustainability aspects in their product development. There are several similarities identified between the two companies in this study and descriptions in prior studies of how manufacturing companies include sustainability aspects in their product development. For example, there are manufacturing companies that systematically include sustainability aspects in product development; however, *what* is systemized differs between the companies.

This research suggests that the easier an aspect can be related to the design of the product the more likely the aspect will be considered by actors in the product development function, such as design engineers. Additionally, this research indicates that the product owner is an important internal actor who affects the inclusion of sustainability aspects in product development, and especially the inclusion of sustainability aspects in product requirements.

Further studies are suggested on how product owners elicit and prioritize sustainability aspects, how these aspects are formulated in product requirements, as well as how, and how commonly, marketing and sales elicit sustainability aspects from customers.

Keywords: Ecodesign, design for environment, environmentally conscious design, design, case study, practice

1 Introduction

Sustainability can be divided into environmental, social and economic aspects (Rogers & Hudson, 2011), and product development (PD) can be described as "the set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product" (Ulrich & Eppinger, 2008). To reduce negative and increase positive environmental, social and economic impact from products, several studies give prescriptive suggestions on how to include one or all of these sustainability aspects in PD. These suggestions include, for instance, methods that can be applied (Lindahl & Ekermann, 2013); how to include environmental aspects in the PD process (Sakao, 2007); that management shall set environmental goals (Ritzén, 2000), especially for PD projects (Boks, 2006) and that certain actors, such as an environmental champion, may be beneficial to have within a company (McAloone, 2000; Ritzén, 2000). The standard ISO 14006 (2011), which guides how to include environmental aspects in PD, while having an environmental management system, gives suggestions related to goals and the process.

To efficiently apply these prescriptive suggestions in a company there is a need to understand the organizational context (Domingo, Buckingham, Dekoninck & Cornwell, 2015; Boks & McAloone, 2009). For example, customization of a method is based on the understanding of the specific organizational context surrounding the supportive method (O'Hare, 2010). A similar thought is presented by Flyvbjerg (2006), who states that there are learning benefits from combining context-dependent knowledge with non-context-dependent knowledge. Context-dependent knowledge can, for instance, be a description of a company's working process (*how they work*), while non-context-dependent knowledge can be a general suggestion of a working process to apply (*how to do something*). There are several prior studies describing how companies include sustainability aspects in PD, such as those by Tingström, Swanström & Karlsson (2006), Poulikidou, Björklund & Tyskeng (2014), Jönbrink et al. (2013), Deutz, McGuire & Neighbour (2013), Sihvonen & Partanen (2016) and Mawle, Bhamra & Lofthouse (2010). However, in general, there seems to exist more research providing prescriptive suggestions on how to include sustainability aspects in PD than descriptions of how it is done (Bovea & Pérez-Belis, 2012).

1.1 Aim

The aim of this paper is to describe how two manufacturing companies include sustainability aspects in their product development, make a comparison between them, and relate findings with prior studies.

1.2 The use of the terms aspect and requirement

In this research, a **requirement** is the same as what Ulrich & Eppinger (2008 p. 72) denominate as a specification, i.e., a "precise, measurable detail [of] what the product has to do". An **aspect** is "a statement, for example[,] information, a need or a constraint, before it has been processed in a requirements development process into a requirement" (Nilsson, 2017 p. XI).

2 Methodology

To fulfil the aim a multiple case study approach was used. Two large manufacturing companies which explicitly stated on their websites that sustainability aspects are included in PD were selected as case companies. Semi-structured interviews were performed at the main PD site of the two companies, which was located in Sweden. A contact person at the companies got a

description of the main questions the interview would deal with, and thereafter selected interviewees. In total, four interviews each lasting about 50 minutes were performed between May and August 2016. Each interview focused on the following four interview questions: *How does the process look when including sustainability aspects in PD? Which actors are involved when including sustainability aspects in PD? What measurable goals does your company have when it comes to including sustainability aspects in PD? Which methods are used when including sustainability aspects in PD?* These interview questions defined the scope and limits of this research; however, the open structure of the interview questions gave the possibility to analyze adjacent, relevant issues brought up by the respondents. During these interviews other questions, mainly regarding challenges when including sustainability aspects in PD, were also asked (published in Paulson and Sundin, 2017). All interviews were recorded, transcribed and summarized. The respondents, each of whom is presented in Table 1, adjusted and verified the interview summaries. Additionally, answers to the interview questions were searched for in the companies' latest sustainability report (from 2015) in order to retrieve more answers and/or verify interview answers. Information indirectly related to the main interview questions, but found relevant for this study, is included in this paper; an example is the role of requirements. The analysis focused on identifying similarities and differences between the companies. In this paper, each of the two cases are to the most extent presented after each other, since the authors believe reading each case as a coherent unit is valuable for the understanding of each company's situation. However, detailed data on actors and methods are presented in the tables in Appendix 1 and 2 to ease reading and comparison between the companies.

Table 1 Presentation of the respondents and their roles at Companies A and B. RA1 means Respondent 1 at Company A. The table is adapted from Paulson and Sundin (2017).

Respondent and his/her role	Experience of Respondent
RA1: Head of environmental management	Worked with environmental issues for 20 years in different positions at Company A
RA2: Project environmental coordinator	Worked with inclusion of environmental aspects in PD projects at Company A for 3 years
RB1: Coordinator of environment, safety, and health	Worked with environment and work environment for 29 years. Worked 15 years at Company B, 8 of those with sustainability
RB2: Manager of the main PD department	2 years in current position. 18 years of experience working as a design engineer and project manager in PD at Company B

3 The Case of Company A

Company A is an international, listed, business-to-business (B2B) and original equipment manufacturer (OEM) with more than 12,000 employees, which develops and manufactures systems. The systems are combinations of products and services and consist of sub-solutions, where the sub-solutions mainly are either (1) developed and manufactured in-house, (2) developed and manufactured by a supplier, or (3) developed in-house and manufactured by a supplier. A component is an example of a sub-solution. This research focuses on the physical products of the system, which are henceforth called *products*.

3.1 The process of how sustainability aspects are included in PD

Company A includes sustainability aspects when developing its products, mainly through requirements from customers and legal aspects. The focus is on phasing out and substituting hazardous chemical products and materials from Company A's products to reduce the risk of losing the supply of critical chemical products and materials. The risk is mainly caused by the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH, 2006) legislation. In general, the process is market driven and a business contract is often signed before major PD activities begin. That is what is presented in this case. In the planning phase, a business case is developed and negotiated with the customer, as seen in Figure 1. The customer's needs are elicited mainly by marketing and sales, with support from the PD function and the product owner.

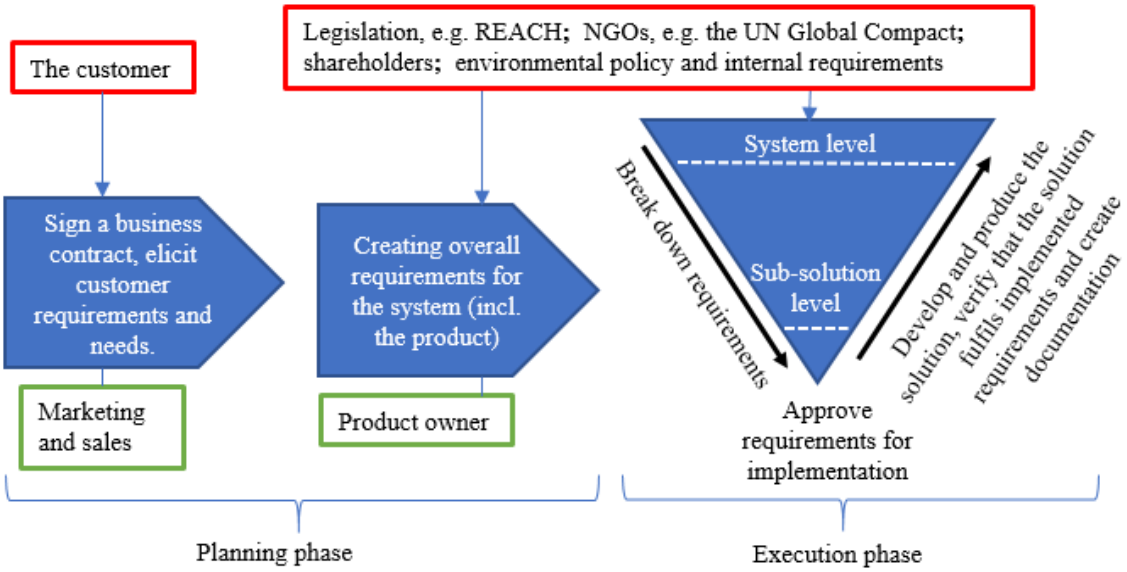

Figure 1 This figure shows an overall description of Company A's PD process. Since it is an overall process, there exist more detailed, underlying and connected processes. The planning phase starts with making efforts to sign a business contract, thereafter overall requirements are created. Systems engineering is performed in the execution phase, in which requirements first are broken down and thereafter approved. Last, the system and its solutions are developed and produced. The execution phase also covers maintenance, until closing the business. The upper boxes include the main stakeholders that affect what sustainability aspects to consider, while the lower boxes include the main internal actors working in the two first steps of the process.

Thereafter, the product owner processes needs into overall requirements for the whole project and system, which includes the product. Only aspects and needs that are processed into requirements will be considered further on in the process. The overall requirements are delivered into the execution phase, in which systems engineering is conducted. In general, employees identify which of the requirements apply to them. Overarching requirements are broken down from a systems level into requirements for each sub-solution. When a requirement is sufficiently broken down it is reviewed and (perhaps) approved by a specific group at a formal meeting. Approving a requirement is a gate that must be passed before a solution to the requirement can be developed. Solutions are developed and verified, both at a system and sub-solution level. Each PD project is obliged to describe in detail how to execute the project in the execution phase, which among other things includes how environmental aspects will be managed. Integrated PD is practiced, which means that actors in the design, manufacturing and purchasing functions work in parallel and together. Despite the inclusion of sustainability aspects in the planning phase of the PD process, RA1 mentioned that the customer's requirements can be scrutinized more than is currently done to identify the customer's

underlying needs. RA1 further described that a life cycle perspective is not applied at Company A but that they would like to have that, and one reason is that RA1 believes there might be legislative requirements on using LCA in future public procurements in the EU.

3.2 Goals and indicators on inclusion of sustainability aspects in PD

Company A does not have formal sustainability-related key performance indicators (KPIs) in PD. However, Company A has the following goals and indicators related to the inclusion of sustainability aspects in PD. First, the organization shall, within a couple of years, have the ability to declare the content of hazardous chemical products and materials per product and/or smallest component, with support of the company's IT system. Second, the actors involved to fulfil environmental requirements, e.g., involved design engineers, purchasers and project managers, shall have awareness about what the REACH (2006) legislation and the environmental requirements mean. Third, 100% of a certain category of the company's products shall comply with the Restriction of the use Of certain Hazardous Substances in electrical and electronic equipment directive (RoHS, 2011), and the company follows up on what percentage of the products in that category comply with RoHS (2011). Fourth, the company is working toward and has additional goals for phasing out chemical products and materials that are or may become restricted or forbidden. Additionally, Company A has ongoing activities to develop UN climate goals (United Nations, 2015) into goals for its own products.

3.3 Aspects, requirements and actors related to sustainability in PD

At Company A, compliance with environmental legislation, e.g. REACH (2006), is currently the most demanding challenge. Solving issues related to such legislation is a necessity for the both short and long-term success of its business, and consequently is a strong focus of the company. Each system can have up to 10,000 requirements to be fulfilled. Managing all requirements for such a system is difficult, and is therefore of key importance at Company A. A specific software (DOORS) is used for managing the requirements.

There are mandatory environmental requirements that all PD projects must fulfil, regardless of the size of the project's budget. Customer requirements are added upon these mandatory environmental requirements. Sustainability aspects are processed into requirements and included in the PD process as any other requirement.

The purchasing function is responsible for selecting suppliers that, among other things, fulfil environmental and social requirements on purchased chemical products, materials and components. However, in the purchasing process design engineers and purchasers work together. The main reason for social requirements, such as no acceptance of child labor in the supply chain, compliance with country-specific water management legislation, and minimizing the content of conflict minerals in the company's products, mainly being handled by the purchasing function is that all solutions and sub-solutions a design engineer decides to buy from a supplier must pass the purchasing function. The same applies for environmental requirements of purchased chemical products, materials and components.

In general, requirements related to the function of the product are prioritized higher than environmental requirements, in situations where a solution that meets both types of requirements cannot be found. The decision of how to prioritize in each situation is made by the owners of the requirements. Consequently, all requirements elicited and specified during the PD process will not be fulfilled.

At Company A, material and manufacturing specialists are involved in the strategic work to phase out and substitute hazardous chemical products and materials. They do it by carrying out investigations and making design-related decisions which pre-specified material and surface treatments design engineers will be able to select. However, design engineers are in general free to come up with solutions that do not require these pre-specified solutions. There are also activities design engineers must do, e.g., design for assembly and design for interchangeability. These obligations are described in guidelines that shall be followed.

3.4 Actors involved when including sustainability aspects in PD

At Company A, sustainability aspects are included in the PD process as any other aspect; therefore, any actor in the company may have to consider sustainability aspects. The purchasing process can be seen as an interweaved unit of the PD process. In total, 18 actors involved when sustainability aspects are included in PD were described. Examples of actors are: the product owner, project environmental coordinators, purchasers, environmental managers, project managers, mechanical design engineers, system safety engineers, systems engineers and material and manufacturing specialists. All 18 actors are listed in Table 1 in Appendix 1.

3.5 Methods applied when sustainability aspects are included in PD

At Company A 26 methods applied when including sustainability aspects in PD are described. Since all environmental requirements are fully integrated with all other requirements, they are managed and fulfilled by applying conventional methods such as CAD, CAM and PDM systems. Additional examples of methods applied are: lists with banned and restricted chemical products and materials, templates for generating product specifications and supplier contracts, design reviews, checklists, supplier code of conduct, audits, full LCA (on customer request and to verify certain requirements), requirements engineering software (DOORS) and a project specific environmental assurance plan. All 26 methods are listed in Table 1 Appendix 2.

An interesting comment from RA1 on the use of conventional methods when including environmental aspects in PD is as follows: *"Environmental aspects are integrated in everything we do. You use your standard [conventional] methods, and you might not be aware that it is environmental requirements, but it is an environmental requirement" (*Authors' translation).

Moreover, RA1 emphasized the need for the integration of environmental requirements into conventional methods: *"Stand-alone solutions do not work in the long run. Therefore, you must integrate [environmental requirements] into all other methods that are in use" (*Authors' translation).

4 The Case of Company B

Company B is an international, listed, B2B and OEM company with more than 10,000 employees, which develops and manufactures products that are mainly mechanical; however, the products include electronic and automatic control functions as well. Company B includes both environmental and social aspects in PD. More than 10 years ago, Company B made a couple of LCAs of its principal products and found that the use phase stands for more than 95% of these products' environmental impact due to energy consumption. The increased degree of energy efficiency of these products' use phase is well aligned with reduced life cycle cost and increased profit for Company B's customers, reduction of the environmental impact from these products' whole life cycle, and increased profit for Company A. Therefore, Company B focuses

on improving the degree of energy efficiency of its principal products' use phase. This case covers Company B's principal products only, which in this paper are called *products*.

4.1 The process of how sustainability aspects are included in PD

The PD process at Company B most commonly starts with the local marketing and sales functions having identified a business opportunity and customer needs that Company B can take, fulfil and make profit out of. In this phase, a systematic search for sustainability aspects is not conducted. The prior LCAs guide which sustainability aspects to focus on. The product owner then compiles a first set of requirements for a product to be developed and initiates a pre-study. The overall PD process is described in Figure 2.

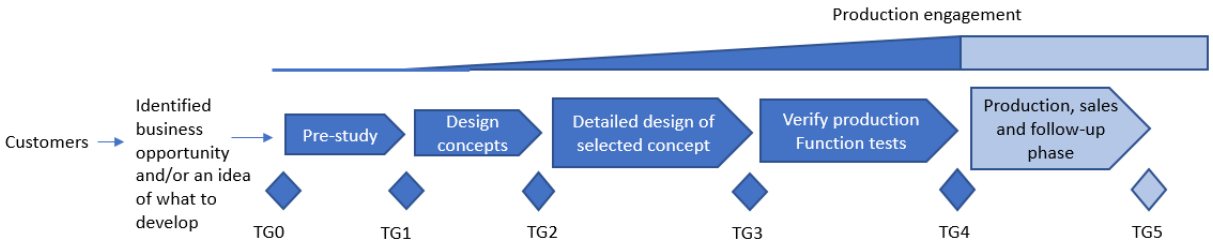

Figure 2 This figure depicts an overall description of the PD process at Company B. Since it is an overall process, there exist more detailed underlying and connected processes. All activities before TG4 are mainly related to the development of the product, while activities after TG4 are mostly related to production and sales. In the end of the design concepts phase, production increases its engagement.

At TG0, it is decided whether a pre-study shall be performed or not; if it is, deliverables from the pre-study are a project and product specification and some other documents. At TG1, the concept development phase starts, which includes design activities. The goal is to select one concept that is believed to have the best possibility to fulfil the requirements. If TG2 gets passed, then a detailed design phase starts. Deliverables are designs of the product and its production processes. Before TG2, most of the concept is developed; after TG2, it is about realizing the concept. When passing TG3, the production processes and the product are tested and verified that they can fulfil the requirements. If all the requirements are fulfilled, then production and sales can start, in parallel with a follow-up phase. The majority of the PD activities related to the product are conducted between TG1 and TG4. Most of the focus on environmental and work environmental aspects, however, is just before and at TG2. A document called the ESH (Environment, Safety and Health) design review, which mainly contains environmental and work environmental aspects, is compiled and presented at TG2. At TG2, the concept must be approved by RB1 (responsible person for sustainability at the company). Sustainability aspects are included in the other toll gates as well, but in those cases are included in ordinary documents that shall be filled in and complied with. The toll gates following TG2 have more of a "follow-up" focus than TG2 does. RB1 wants sustainability aspects to be considered earlier than is done today to increase the affect such considerations may have on the company's products, preferably already in the dialogue with customers, before TG0.

4.2 Aspects, requirements and actors related to sustainability in PD

The most important customer need, and one which guides PD at Company B overall, is to fulfil the main functional requirements of their products with as *few technical problems and as little life cycle cost* as possible for the customer. That need is processed into *increasing the products' degree of energy efficiency, fitting more functionalities into the same product, and minimizing*

unplanned and planned stops. The first, i*ncreasing the degree of energy efficiency,* is the most important.

Sustainability aspects are integrated into the ordinary PD and purchasing processes, and thereby affect all of Company B's products. There is no green line product portfolio. Environmental, social and business ethical aspects related to the suppliers and the supplied goods are managed in the purchasing process only, for instance, declarations about where product materials come from and that no forced labor is applied in the supply chain. The supply chain is pointed out as key for future improvements of Company B's sustainability efforts. The purchasing function has the responsibility to make the supplied goods fulfil several social aspects of the product, e.g., human rights, no child labor and no forced labor in the supply chain. Both respondents think that it does not make much sense to make design engineers consider such social aspects, since such social aspects are difficult to relate to the design of the product. However, design engineers indirectly affect health and safety conditions in production, since a certain design may require a production process with health or safety issues. Design engineers also affect product safety, although this is not seen as a typical social aspect by the respondents of Company B. Economic aspects in PD are mainly life cycle cost (LCC) for the customer and profit, and are managed in the PD process as usual.

Company B is not covered by the directive on energy-related products (ErP, 2009); however, the customers may not always know that and ask for compliance with ErP (2009) anyway. Additionally, fulfilling this directive and other types of classification related to the energy efficiency support the marketing of Company B's products. It is for the same reason negative for Company B's business if competitors fulfil energy-related directives and classifications and Company B does not. The risk that Company B's products will be covered in future energy-related legislation also drives efforts to increase the degree of energy efficiency of the products.

4.3 Goals and indicators on inclusion of sustainability aspects in PD

Company B has two clear goals related to the inclusion of sustainability aspects in PD. The first goal is that in the company's largest business areas, the degree of energy efficiency of sold products on average shall be increased by 1%, which affects what Company B develops and sells. The second goal is that the percentage of sales from new products that are launched in the past five years shall increase and reach 25% by the year 2020. This goal drives innovation and reduces the environmental impact of the company's products, since newer products have a higher degree of energy efficiency than older ones.

There are also important indicators for Company B. One is that there are measurements on how often Company B's employees are hurt by accidents at work. Another is that Company B measures how many of its employees are on sick leave; sick leave shall decrease over time, and the vision is zero. Yet another is that Company B follows up on customer/end user accidents. When accidents occur, the PD function is informed. If necessary, the product is modified and/or safety information in manuals is improved. The vision is zero accidents.

4.4 Actors involved when including sustainability aspects in PD

At Company B, 31 actors involved when sustainability aspects are included in PD were described. Examples of actors are: the product owner, employees in the ESH & sustainability function, purchasers, the project manager, design engineers, the product safety function, top management, the marketing department, production and production representatives. All 31 actors are listed in Table 1 in Appendix 1.

4.5 Methods applied when sustainability aspects are included in PD

At Company B there are 13 methods described, which are applied when including sustainability aspects in PD. For example, Company B includes environmental and work environment (safety and health) questions in checklists and other documents that are mandatory to fill in/write for making progress in the PD process. The aim of the checklists and documents is mainly to force the project members to reflect upon the product's impact on the environment and work environment, and perhaps adjust the product according to those reflections. Additionally, the checklists and documents remind project members to consider the environmental requirements, for example not using materials that include restricted chemicals. Additional examples of methods applied are: lists with banned and restricted chemical products and materials, product specification templates, design reviews (especially the ESH-design review at TG2, see Figure 2), supplier code of conduct, audits, full LCA and customized software and calculations to increase the degree of energy efficiency of Company B's principal products. All 13 methods are listed in Table 1 in Appendix 2.

Company B has tried to include social aspects in PD using an assessment method that uses a weighted index. The index included social, economic and environmental aspects. However, the method was not found applicable enough for design engineers or for PD in general. RB1 believes the reason is that it was difficult to see which social aspects are applicable for a design engineer, since many of the social aspects occur in the supply chain.

There is no clear request for new or better methods. However, RB1 mentioned that methods that could help Company B include sustainability aspects even earlier in the PD process than it currently does would be interesting to test.

5 Comparison between the two companies and discussion

In this section, Companies A and B are compared, findings are related to prior studies and the methodology is critically reviewed.

5.1 The process of systematic inclusion of sustainability aspects in PD

Companies A and B include sustainability aspects in their PD systematically; however, which sustainability aspects they focus on differ, as well *what* is systemized. For instance, Company A systematically involves project environmental coordinators in PD projects and generates pre-specified solutions for environmental and legal requirements. Company B systematically includes sustainability aspects using, for instance, product specification templates and by conducting ESH design reviews. While Company B applies a life cycle perspective in PD, Company A appears not to. Both companies use a stage-gate PD process. Systematic inclusion of sustainability aspects in companies' ordinary PD processes, and a difference of what is systemized, has also been identified in previous cases (see, e.g., Poulikidou et al., 2014 and Tingström et al., 2006). The data from Company A suggests that LCA is not necessarily conducted at manufacturing companies to achieve a life cycle perspective in PD.

5.2 Companies' views on what a sustainability aspect and requirement are

Social aspects are mainly seen as health and safety in one's own workplace and no forced labor, child labor and negative health and safety aspects in the supply chain. All respondents associate social aspects primarily with the supply chain, and therefore consider social aspects of products mainly as a responsibility of the purchasing function rather than design engineers. The

perspective that social aspects are the responsibility of some actor other than design engineers, and the difficulties to come up with social aspects easily applicable for design engineers, were also identified at a manufacturing company studied by Mesquita, Hallstedt & Broman (2016). Similarly, Tischner & Charter (2001 p. 83) discuss how social aspects are usually managed by a central function, rather than by actors in the daily operations. However, product safety can be seen as a social aspect too (Joung, Carrell, Sarkar & Feng, 2012), which is considered by, e.g., system safety engineers at Company A and design engineers at Company B.

Environmental aspects are mainly phasing out hazardous chemical products and materials (Company A) and reducing energy consumption from the product's use phase (Company B). These environmental aspects are managed by actors in the PD function, such as design engineers, environmental coordinators and the purchasing function. The environmental engineers guide and support the inclusion of environmental aspects in PD. The PD function seems to be engaged more in environmental aspects than social aspects, except for the product safety aspects. Despite the studied companies' perspectives on which actors having the responsibility to manage social and environmental aspects (see previous paragraph), the data from both companies in this research suggest that it is the ease of relating *any* type of aspect to the design of a product that matters if the aspect will be considered by actors in the PD function, such as design engineers.

Both companies in this research seem to focus on sustainability aspects that reduce economic risk, for example compliance with water management legislation (Company A) and future energy related legislation (Company B). In addition, Company B includes a focus on sustainability aspects that provide economic opportunities, e.g., develop energy efficient products that comply with legislation that they are not covered by, to increase competitiveness. The focus on risk and opportunities helps the companies to survive and is similar to how Tischner & Charter (2001 p. 78) describe sustainable businesses in the private sector, which have to adapt to the same economic requirements as any other business in the private sector to survive. Economic aspects seem to mainly be short and long-term profit, and are not explicitly described by the respondents as sustainability aspects. Instead, short and/or long-term profit seem to be a prerequisite for the inclusion of *any* sustainability aspect in PD, which is also a perspective described by Byggeth & Hochschorner (2006). A risk and opportunity perspective is also identified at companies studied by Poulikidou et al. (2014). Additionally, Poulikidou et al. (2014) found that risks and opportunities may be important enablers for the inclusion of environmental aspects in PD.

Business ethical aspects, such as no corruption, are important sustainability aspects for both companies, but are not classified by the respondents as environmental, social or economic aspects. Similar thoughts are described by Björklund (2012, p. 43) who discusses that business ethical aspects can be seen as economic aspects, but that there is a lack of consensus on how to classify them, since some ethical aspects can be seen as social aspects as well.

5.3 Goals on the inclusion of sustainability aspects in PD

Both companies have sustainability goals that are in line with sustaining and/or growing their businesses. Defining sustainability goals for a PD project is mandatory for ABB (Tingström et al., 2006). However, how these goals are formulated and prioritized in ABB's PD projects is not described.

The goals described by Companies A and B on including sustainability aspects in PD apply mainly to a portfolio of products rather than to a single product or PD project (not meaning that PD projects do not get affected by these goals). Additionally, the goals imply that both companies to some extent include sustainability aspects in their product strategies. This is similar to how Scania, a large truck manufacturing company studied by Ölundh & Ritzén (2004), works.

5.4 Actors involved when including sustainability aspects in PD

At Companies A and B, the marketing and sales functions are the main actors searching for customer needs; however, according to respondents at both companies, sustainability aspects are not systematically searched for by the marketing and sales. There are prior studies reporting on manufacturing companies that have similar potential as Companies A and B to include sustainability aspects earlier in their PD processes than they currently do (see, e.g., Deutz et al., 2013 and Lee-Mortimer & Short, 2009). In contrast, there are manufacturing companies that include sustainability aspects already in the planning phase of their PD processes, see, e.g., Tingström et al. (2006) and Poulikidou et al. (2014), but if or how marketing and sales are involved is not described in these studies. Consequently, there seems to be a potential to learn more about how to include sustainability aspects in the planning phase of the PD process by studying how, and how commonly, the marketing and sales functions elicit sustainability aspects from customers.

Ten actors involved when sustainability aspects are included in PD are mentioned by both companies, see Table 1 in Appendix 1, and they are: (1) customers; (2) legislative authorities; (3) the product owner; (4) project managers; (5) purchasers; (6) system/product safety engineers; (7) joint action groups; (8) design engineers; (9) top management; and (10) environmental coordinators, who guide and support the inclusion of environmental aspects and requirements in PD. There are both internal and external actors mentioned, and the internal actors come from several functions of the company.

The purchasing function is seen by both companies in this research as an important actor for the inclusion of sustainability aspects in PD. The reason is that social and environmental aspects related to the supplied chemical products, materials and components of products are mainly managed by the purchasing function rather than by the PD function.

The product owners at Companies A and B are responsible for the economic success of the product and compiles the first set of requirements for the product. The latter corroborates with Haines (2013, p. 64) who states that product owners may define early target requirements for the product. At Company B, product owners, also referred to by Ulrich & Eppinger (2008) as portfolio management or product management, make strategic decisions on the company's product portfolio. According to Ölundh & Ritzén (2004) environmental aspects need to be considered in the business and product strategy to be included in the product requirements. Consequently, the product owner seems to be an important actor for the inclusion of sustainability aspects in PD in general and in product requirements in particular. This study has not revealed details of how product owners work. Therefore, to better understand how sustainability aspects are included in product requirements, this research suggests further studies on how product owners elicit and prioritize sustainability aspects, and on how these aspects are formulated in early product requirements. Such studies would also contribute to fill the research gap identified by Brones & Monteiro de Carvalho (2015) on the inclusion of environmental aspects in portfolio management.

5.5 Methods applied when including sustainability aspects in PD

Companies A and B describe 26 and 13 methods, respectively, which they use when including sustainability aspects in PD. Eight of the methods are being used by both companies, see Table 1 in Appendix 2, and they are: the supplier code of conduct and audits, templates for generating product specifications, design reviews, lists with banned and restricted chemical products and materials, product safety analysis, checklists, full LCA and meetings and questionnaires to get feedback from stakeholders. Lists with banned and restricted chemical products and materials are, for example, used at the large manufacturer Philips as well (Stevels, 2007 p.89). Checklists are also applied by manufacturing companies in Finland (Sihvonen & Partanen, 2016). Companies A and B conduct full LCAs, however for different purposes and in different frequency. Jönbrink et al. (2013) describe a large Swedish vehicle manufacturer that conducts LCA (here interpreted as full LCA). Checklists and LCA are described as ecodesign methods by Lindahl & Ekermann (2013) and Bovea & Pérez-Belis (2012).

Some methods applied by Companies A and B are not commonly referred to as ecodesign methods or methods for sustainable PD. These methods are *the supplier code of conduct*, *templates for generating product specifications*, *design reviews*, *meetings and questionnaires* (to get feedback from stakeholders), and *product safety analysis*. Sihvonen & Partanen (2016) and Mesquita et al. (2016) report on manufacturing companies that apply environmental requirements on suppliers. Mesquita et al. (2016) report on social requirements on suppliers as well. Sihvonen (personal communication, February 13, 2018) stated that 82% of the companies studied in Sihvonen & Partanen (2016) used a supplier code of conduct, but as a framework for the actual requirements on suppliers. van Weele (2012, p. 585-586) brings up the example of Philips, a manufacturing company that uses a supplier code of conduct to manage sustainability aspects in the supply chain in a similar way as both Companies A and B do.

Some methods applied by both Companies A and B are classified by the authors as conventional engineering methods, for example the *design reviews*, *templates for generating product specifications*, and the *meetings and questionnaires* (to get feedback from stakeholders). The reason for this classification is that these methods are considered methods that can be used in PD without the inclusion of environmental or social aspects. Additional conventional engineering methods applied when including sustainability aspects in PD are CAD, CAM, requirements engineering software, PDM and ERP systems applied by Company A, and the mathematical efficiency calculations applied by Company B. Similarly to both Companies A and B, vehicle manufacturers in Sweden see many of their conventional engineering methods as important and desired means for reducing the environmental impact from their products and complying with environmental requirements (Poulikidou et al., 2014).

5.6 Methodological implications on the results

The data which this study is based on comes mainly from the interviews, since the data in the sustainability reports mainly included data that described inclusion of sustainability in the company on an overall company level rather than on a PD-level. The respondents and the sustainability reports contributed with data that complemented each other rather than being in conflict. The numbers of actors involved and methods applied depend on how actors and methods are grouped by the authors and shall therefore be seen as approximate.

To achieve credible descriptions and conclusions it is important to search for threats of validity (Maxwell, 2013). The following major threats of validity are identified for this research:

- The respondents and interviewer interpreting the interview questions and answers differently. This has been managed mainly by letting the respondents review and adjust the case descriptions.
- Too few sources of data to identify possibly contradictory data. Focus was on selecting respondents with suitable knowledge for the interviews, rather than many respondents. The data represents the perspectives of the respondents and authors of the sustainability reports. What would have been the results if also a designer, product owner and purchaser were interviewed?
- The data collected from the sustainability reports might be biased towards a positive presentation of the companies' work with sustainability. The implication is that the data originating solely from the sustainability report, such as the methods meetings and questionnaires (no. 8 in Table 1 in Appendix 2), might have lower validity than the data originating from the respondents.

All but one respondent were managers (RA1, RB1, RB2), which could have biased the result towards emphasizing strategies rather than details of PD-projects, for example that described sustainability related goals apply mainly to a portfolio of products rather than to products or PD projects, see chapter 5.3 "Goals on the inclusion of sustainability aspects in PD". However, since RA2 work in the projects and RB2 had years of experience from working in and managing projects, they are expected to have enough insights from the projects to balance this bias. Additionally, their descriptions were in line with the other two respondents, i.e. RA1 and RB1.

Roughly half of the data given by RA1 and RA2 that describes the PD process of how sustainability aspects are included in PD at Company A, was considered the same. The remaining data describing the PD process was complementing rather than contradicting. The PD process description in Figure 1, comes mainly from RA1 since that was the only description covering the planning phase. Both respondents at Company B gave similar descriptions of their PD process. However, complementing data from RB1 and RB2 exist also in their descriptions of Company B's PD process. The PD process description in Figure 2 originates from internal process descriptions of how to work at Company B. The authors' opinion is that the PD process descriptions reflect how they try to work, and mostly do work, and that each PD project may include exceptions.

6 Conclusion

This paper provides two novel context-dependent descriptions of *how* large manufacturing companies include sustainability aspects in PD. The following six similarities between the two companies in this study and descriptions in prior studies of how manufacturing companies include sustainability aspects in PD have been found interesting to bring up:

- There are manufacturing companies that systematically include sustainability aspects in PD. However, *what* is systemized differs between the companies.
- Focus seems to be on sustainability aspects that reduce the company's economic risk and create economic opportunities, to ensure the company's survival.
- Short and/or long-term profit seems to be a prerequisite for the inclusion of any sustainability aspect in PD.

- Social aspects are mainly associated with the supply chain and the company's own workplace; however, that depends on what is interpreted as an environmental or social aspect.
- Goals on inclusion of sustainability aspects in PD apply mainly to a strategic level rather than to a single PD project.
- There are conventional engineering methods applied by manufacturing companies, which can support the inclusion of sustainability aspects in PD. However, these methods are seldom referred to as ecodesign methods or methods aimed at developing products that are more sustainable.

One difference identified between the two companies in this study and most of the companies described in the prior studies reviewed, is that one company in this study does not seem to apply a life cycle perspective in PD.

This research suggests that the easier an aspect can be related to the design of the product, the more likely the aspect will be considered by actors in the PD function, such as design engineers. Additionally, this research indicates that *product owners* are important internal actors for the inclusion of sustainability aspects in PD, and especially for the inclusion of sustainability aspects in product requirements. However, there seems to be a lack of studies on the role of product owners for the inclusion of sustainability aspects in PD and product requirements. Therefore, studies on how product owners elicit and prioritize sustainability aspects, and how these aspects are formulated in early product requirements are suggested. Furthermore, more research is suggested on how, and how commonly, marketing and sales elicit sustainability aspects from customers.

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Appendix 1

Table 1 Actors involved at Companies A and B when sustainability aspects are included in product development, according to the two respondents at each company and descriptions in each company's latest sustainability report. The first ten actors (grey fields in the left column) represent actors which the authors consider exists at both companies and are therefore written in the same row.

No.	Actors involved at Company A	Actors involved at Company B
1	the customer	customers
2	legislative authorities	national and regional authorities that develop legislation and directives, e.g. the EU that generated the ErP (2009)
3	the product owner, an internal actor who creates overall requirements for the product and is responsible for its success	the product owner, the internal actor responsible for a part of the product portfolio at Company B
4	project and sub-project managers	the project manager, responsible for the PD project from TG0 and ensuring that checklists are answered
5	purchasers	purchasers, especially for purchased components, electronics and new types of materials
6	system safety engineers	the product safety function, which guides the PD function in questions regarding product safety aspects, e.g. safety in the use phase
7	joint action groups within trade organizations to solve problems together, e.g. related to phasing out hazardous chemical products and materials	joint action groups with other companies
8	a large variety of engineering roles, who develop solutions fulfilling the requirements, e.g. mechanical design engineers	design engineers, since they develop solutions that fulfil requirements
9	top management	top management, who affect the inclusion of sustainability aspects in company goals and strategies
10	environmental managers at different levels, environmental coordinators (support inclusion and fulfillment of environmental aspects and requirements in any activity in the company), project environmental coordinators (support inclusion of environmental aspects and requirements in projects only, which are mainly PD projects)	employees in the ESH & sustainability function, e.g. RB1
11	the shareholders	end users

12	Non-Governmental Organizations (NGOs)	the project owner, who initiates the project and does the necessary activities for passing TG0
13	the owners of requirements	production and production representatives, since they may only approve solutions that require chemical products and materials that are safe enough to use in production. Additionially, since they supports the development and introduction of, e.g. more energy efficient products
14	the chief engineer, who has often the role of approving requirements for implementation and is ultimately responsible for fulfilling legal environmental requirements	suppliers, since they are obliged to fulfil Company B's sustainability requirements
15	the systems engineers, who define the requirements (e.g., environmental requirements that a sub-solution shall fulfil) and are the owners and buyers of both in-house developed and purchased sub-solutions	the ESH functions, which support the PD project to, e.g. answer checklists
16	the chemical coordinators, who can support the projects in questions related to the use of chemicals	the coordinator of environment, safety and health, since this role carries through LCAs, drives the generation of EDPs and has a dialogue with PD regarding sustainability aspects of the product
17	several functions and positions in the top management segment	different levels of managers, since they support and strive to fulfil the company's sustainability goals
18	material and manufacturing specialists	the product documentation function
19		sales subsidiaries, which have a dialog with the parent company regarding how to market and what to say about the product
20		the function within PD that manage standards and approvals
21		working groups in the EU commission, which discuss and affect future legislation
22		the Sustainability Committee at Company B, which affects the sustainability initiatives that Company B shall commit to
23-24		the PD and sales function, since they support the development and introduction of, e.g. more energy efficient products
25		the marketing department, since it supports the development and introduction of, e.g. more energy efficient products
26		the internal Nominating and Governance committee
27-31		academia, other companies, NGOs, local governments and innovators

Appendix 2

Table 1 Methods applied at Companies A and B when including sustainability aspects in product development, according to the two respondents at each company and descriptions in each company's latest sustainability report. The first eight methods (grey fields in the left column) represent methods which the authors consider exist at both companies and are therefore written in the same row.

No.	Methods applied at Company A	Methods applied at Company B
1	suppliers code of conduct, audits and questionnaire audits (covers environmental, social, business ethical aspects, information protection and trade compliance aspects)	suppliers code of conduct, on-site audits and questionnaire audits (covers environmental, social, information protection and business ethical aspects)
2	templates for making sure general and mandatory requirements are included when product specifications and supplier contracts are generated	product specification templates with prespecified questions regarding environment and work environment
3	design reviews at gates	design reviews, especially the ESH design review at TG2
4	internal lists with a compilation of banned and restricted chemical products and materials, based on, e.g., REACH (2006) and RoHS (2011)	internal lists with a compilation of banned and restricted chemical products and materials, based on, e.g., REACH (2006) and RoHS (2011)
5	product safety analysis (covers mainly safety for the user and environment)	the product safety analysis, which is conducted between TG1 and TG2 in the PD process and is required for being able to CE-mark the product (focus is safety for users, maintenance personnel, and people that can be affected by accidents during transportation)
6	checklists to confirm whether, e.g. hazardous chemical products and materials are accounted for or are phased out	checklists and other documents, to force project members to reflect upon the products' environmental and work environmental impact, which ultimately leads to adjustments of the product
7	full Life Cycle Assessment (LCA), on customer request, and to verify certain requirements, and not for implementing a life cycle perspective in PD	full LCA, for EDPs and in the prior LCAs made on Company B's principal products
8	meetings, questionnaires and various other dialogue forums, in order to get feedback and thoughts from stakeholders (most important are aspects related to business ethics, trade compliance and environmental innovations)	surveys and interviews with, e.g., society, customers, and end users to get feedback regarding Company B's activities and products
9	environmental impact assessments, when required by a customer	comparative LCA
10	the purchasing process, since it supports PD in getting sustainability	simplified LCAs with weighted single index (Environmental Load Unit), which

	information on material and suppliers (covers environmental, social and economic aspects)	was earlier performed in the product development projects but not any longer due to the results always showing that that the energy consumption in the use phase stands for the majority of the environmental impact
11	corruption risk analysis, performed by market management	environmental product declaration (EPD) (mainly for marketing)
12	conflict mineral policy	labelling about how to use the product safely, how to recycle it, and how to dispose it
13	meetings with other companies having the same supplier as Company A, to make them adopt Company A's environmental requirements as their own	customized software and calculations to increase the degree of energy efficiency of Company B's principal products
14	cooperation within the branch to develop Company A's anti-corruption and environment work	
15	requirements engineering software (DOORS)	
16	project-specific process description about how to manage environmental requirements in the project	
17	environmental assurance plan, which describes all environmentally-related requirements for a project	
18	environmental requirements included in documents for each supplied component	
19	education is here seen as a method, which is offered to employees, including PD personnel. (covers export and anti-corruption rules)	
20	CAD	
21	CAM	
22	enterprise resource planning (ERP) system	
23	product data management (PDM) system	
24	buying information from external databases	
25	component databases	
26	following and developing standards	