Inclusion of sustainability aspects in product development at manufacturing companies

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**INCLUSION OF SUSTAINABILITY ASPECTS IN
PRODUCT DEVELOPMENT AT MANUFACTURING
COMPANIES**

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ABSTRACT

Due to current consumption and production patterns of products, pressure on already constrained natural resources, an increasing global population, increasing concentrations of greenhouse gases in the atmosphere and reduced access to clean water globally, studying manufacturing companies' inclusion of sustainability aspects in their product development becomes important.

The aim of this thesis is to expand current knowledge on the inclusion of sustainability aspects in product development at manufacturing companies. More specifically, the expansion of current knowledge covers *how* manufacturing companies include sustainability aspects in product development, the *challenges* manufacturing companies may face when including sustainability aspects in product development, and the *reasons* for these challenges.

To fulfil this aim, a literature study and a multiple case study were conducted at two international, listed, manufacturing companies in Sweden. Empirical data was collected using semi-structured interviews with two employees at each company and by analyzing the companies' latest sustainability report.

Empirical results include two context-dependent descriptions of how manufacturing companies include sustainability aspects in product development, 21 challenges the companies face, and 14 reasons for those challenges.

Conclusions include: (1) the role of conventional methods when including sustainability aspects in product development has been largely ignored in prior research; (2) a company's *product owner* influences the inclusion of sustainability aspects in product development, and in product requirements in particular; (3) the following three challenges are proposed incorporated in a comprehensive framework of challenges that has been developed in prior research:

- *Making suppliers fulfil the sustainability requirements that are placed on them.*
- *Transforming sustainability aspects, or general goals, into measurable requirements that contribute to reduced environmental impact from products while at the same time contributing to competitive profit.*
- *Identifying how to reach economic goals more efficiently with a more sustainable initiative or solution than other initiatives.*

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APPENDED PAPERS

The following publications were written during the research for this thesis:

PAPER I Paulson, F. and Sundin, E. (2018), Inclusion of sustainability aspects in product development – two industrial cases from Sweden. Proceedings of *NordDesign 2018 - Design in the era of digitalization*, Linköping, Sweden, Aug 14-17.

In this thesis, PAPER I is updated with a new reference to PAPER III.

PAPER II Paulson, F. and Sundin, E. (2015), Challenges and trends within eco-design. Presented at *EcoDesign2015 - 9th International Symposium on Environmentally Conscious Design and Inverse Manufacturing*, Tokyo, Japan, Dec 2-4.

PAPER III Paulson, F. and Sundin, E. (2019), Challenges when including sustainability aspects in product development at two large manufacturing companies in Sweden. In the E-book proceedings of *Going Green EcoDesign 2017 – 10th International Symposium on Environmentally Conscious Design and Inverse Manufacturing – New Technologies and Eco-innovation Towards Sustainability*. Tainan, Taiwan, Nov 29 – Dec 1. *In press*.

Contribution in the papers:

Fredrik Paulson is the main author of all three appended papers.

PAPERS I and III

Fredrik Paulson developed the ideas of the papers, developed the research design, conducted the majority of the work identifying and selecting the research methodology and the case companies, conducted the research, and wrote the papers. Erik Sundin supported the identification of case companies, selection of research methodology, development of interview questions and writing the papers.

PAPER II

Fredrik Paulson conducted the literature study and wrote the majority of the paper. Erik Sundin developed the idea for the paper and supported the execution of the literature study and the writing.

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Paper I

Paper II

Paper III

TERMINOLOGY USED IN THIS THESIS

ACTOR

“A participant in an action or process” (en.oxforddictionaries.com, n.d.).

ASPECT

“... implies 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).

BARRIER

Anything that limits the ability to do or achieve something specific.

CHALLENGE

“Something that needs great mental or physical effort in order to be done” or achieved (adapted from dictionary.cambridge.org, n.d.).

DESIGNER

“A person who plans the look or workings of something prior to it being made, by preparing drawings or plans” (en.oxforddictionaries.com, n.d.).

DESIGN RESEARCH METHODOLOGY (DRM)

Refers to the Design Research Methodology by Blessing and Chakrabarti (2009).

ECODESIGN

“integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle” (ISO 14006:2011).

ECODESIGN METHOD

“Any systematic means for dealing with environmental issues during the product development process”, adapted from Baumann et al. (2002).

ENVIRONMENTAL REQUIREMENT

A necessary condition that when fulfilled is considered to reduce the environmental impact.

ENVIRONMENT, SAFETY AND HEALTH

“... aims to prevent and reduce accidents, emergencies, and health issues at work, along with any environmental damage that could result from work practices” (safeopedia, n.d.).

LIFE CYCLE ASSESSMENT (LCA)

The “*compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle*” (ISO 14040:2006).

MANUFACTURING COMPANY

A company that develops and manufactures products.

METHOD

A means, tool, or systematic way of working.

PRODUCT DEVELOPMENT

“... *the set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product*” (Ulrich and Eppinger (2008).

PRODUCT DEVELOPMENT PROCESS

“*The sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product*” (Ulrich and Eppinger, 2008).

PRODUCT OWNER

An actor responsible for the economic success of a product, or a portfolio of products (adapted from Robertson and Robertson, 2013).

PRODUCT REQUIREMENT

A statement that describes “... *in precise, measurable detail what the product has to do*” (adapted from Ulrich and Eppinger, 2008).

PRODUCT SPECIFICATION

A compilation of all product requirements.

REQUIREMENT

“*A thing that is compulsory; a necessary condition*” (en.oxforddictionaries.com, n.d.).

SUSTAINABILITY

A target situation in which humanity on earth lives in a way that can be maintained.

SUSTAINABILITY ASPECT

Any aspect that affects the possibility to achieve a situation in which humanity on earth lives in a manner that can be maintained. *Environmental, social and*

economic aspects are here considered to be three general categories of *sustainability aspects* (inspired by Elkington, 1999).

SUSTAINABILITY REQUIREMENT

A necessary condition that when fulfilled is considered to contribute to achieving a situation in which humanity on earth lives in a way that can be maintained.

TRIPLE BOTTOM LINES (TBL)

Explains what a company has to consider, do and account for, to sustain and also contribute to sustainability. The triple bottom lines are environmental quality, social justice and economic prosperity. (Elkington, 1999)

KEY PERFORMANCE INDICATOR (KPI)

A metric that “*shows how well an economy, company, ... [or] project, etc. is doing*” (adapted from dictionary.cambridge.org).

1 INTRODUCTION

This chapter introduces and motivates the research at an overall level. Key concepts are explained and the aim, research questions and limitations are presented.

1.1 BACKGROUND

The use of products contributes to many positive aspects of peoples' lives. For example: by using a car one can visit friends who live far away, and a computer can provide access to education. Additionally, designing, manufacturing and selling products create jobs that give people an income. However, in addition to these positive aspects, the consumption of products has consequences, such as (negative) environmental impact (see, e.g., USEPA, 2006; Lindahl et al., 2000) and (negative) social impact (impact on people and society) (see, e.g., Griebhammer et al. (2006) and Ekener-Petersen and Finnveden, 2013). Impact occurs throughout a products' entire life cycle, see Figure 1.

Figure 1 An overall description of a product's life cycle and its effects on social and environmental impact. The picture is a result of adapting and merging descriptions by Lindquist (2014), Lindahl et al. (2000) and Ekener-Petersen and Finnveden (2013).

According to the United Nations (2018), current consumption and production patterns are not *sustainable*¹ and must change, otherwise irreversible damage of the environment will occur. In particular, because the global population is growing and the living standard is increasing, which requires more of “*already constrained natural resources*” (United Nations, 2018).

To make the change towards more sustainable consumption and production patterns, approaches such as *ecodesign*² are available for manufacturing companies.

Even though a large volume of support *methods*³ (Baumann et al., 2002; Pigosso et al., 2015) and research on the inclusion of environmental aspects in product development is available, inclusion of environmental aspects in product development is not mainstream. For example, almost 20 years ago Tukker et al. (2001) found that environmental considerations in product development practices in Europe was scarce. Some years later, Jönbrink et al. (2013) found that structured and strategic integration of environmental aspects in product development was still lacking at manufacturing companies in Sweden. Additionally, Sihvonen and Partanen (2016) found that considerations of environmental aspects in product development at manufacturing companies in Finland was still not mainstream. These findings by Tukker et al. (2001), Jönbrink et al. (2013) and Sihvonen and Partanen (2016) indicate there are challenges and barriers to the inclusion of environmental aspects in product development at manufacturing companies.

Prior studies have investigated challenges and barriers that manufacturing companies can face when including sustainability aspects (most studies focus on environmental aspects) in their product development. See, for example, the studies by Hallstedt and Thompson (2011), Bey et al. (2013) and Jönbrink et al. (2013). Inclusion of *sustainability aspects*⁴ in product development means here that sustainability aspects, for example a need to reduce carbon dioxide emissions, are *considered* by the people participating in the work to develop a product.

Even though there are prior studies that have investigated this type of challenges and barriers, it is presumed that there are additional challenges manufacturing

¹ A target situation in which humanity on earth lives in a way that can be maintained.

² “*integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle*” (ISO 14006:2011).

³ A means, tool or systematic way of working.

⁴ Any aspect that affects the possibility to reach a situation in which humanity on earth lives in a manner that can be maintained, e.g., environmental, social and economic aspects.

companies can face when including sustainability aspects in product development. Moreover, most descriptions of the challenges described in prior studies lack information on the causes of the challenges. Such information would aid in addressing these challenges. Therefore, to increase the knowledge on these challenges and their causes, further studies are needed.

There are prior studies that describe how manufacturing companies include sustainability aspects in their product development, see e.g., Tingström et al. (2006), Deutz et al. (2013), Sihvonen and Partanen (2016), Jönbrink et al. (2013), Poulikidou et al. (2014) and Stevels (2007). However, most studies focus on environmental aspects rather than widening the scope to sustainability aspects. Additionally, few studies describe the process, methods applied and *actors*⁵ involved when sustainability aspects are included in product development. Even fewer studies describe what sustainability goals manufacturing companies apply to products. It is therefore important to study how manufacturing companies include sustainability aspects in their product development.

To include environmental aspects in product development it is necessary to understand the company context (Domingo et al., 2015; Boks and McAloone, 2009; Boks and Stevels, 2007). However, there are few studies that focus on understanding the company context of the inclusion of environmental or sustainability aspects in product development. Furthermore, Flyvbjerg (2006) argues that learning is enhanced by complementing the knowledge generated from general theories with context-dependent knowledge.

1.2 AIM

The aim of this licentiate thesis is to expand current knowledge on the inclusion of sustainability aspects in product development at manufacturing companies.

1.3 RESEARCH QUESTIONS

To meet the aim of this thesis, the aim has been broken down into three research questions.

⁵“A participant in an action or process” (en.oxforddictionaries.com, n.d.)

RQ1 How do manufacturing companies include sustainability aspects in their product development?

RQ1 expands the knowledge on *how* manufacturing companies include sustainability aspects in product development in real life and focuses on:

- the process of inclusion of sustainability aspects in product development
- the sustainability aspects that are focused on
- the actors involved when sustainability aspects are included in product development
- the goals the manufacturing companies have for inclusion of sustainability aspects in product development
- the methods applied when including sustainability aspects in product development

Additionally, RQ1 contributes with context to RQ2 and RQ3.

RQ2 Which challenges do manufacturing companies face when including sustainability aspects in their product development?

RQ2 expands the knowledge on which challenges manufacturing companies can face when including sustainability aspects in product development.

Going further in the exploration of these challenges. RQ1 concerns the context of the challenges and RQ3 concerns determining the cause of the challenges.

RQ3 Why do manufacturing companies face challenges when including sustainability aspects in product development?

RQ3 expands the knowledge on the cause of the challenges identified in RQ2.

1.4 LIMITATIONS OF THE RESEARCH

The empirical data covers two listed, international manufacturing companies, whose main products are developed and manufactured in Sweden.

The empirical data comes from a total of four interview respondents (two at each of the two manufacturing companies) and two sustainability reports (one from each company).

The products developed and manufactured by the manufacturing companies studied in this thesis consist of physical components, software and services.

However, this thesis focuses on the physical component elements of the products, not the software and services.

This thesis excludes prior research and theory on how manufacturing companies *should, or could*, include sustainability aspects in product development. This thesis instead focuses on understanding how manufacturing companies work in real life, the challenges they face and the causes of these challenges.

2 RESEARCH METHOD

This chapter presents the research methods and the relations between research questions and research methods.

2.1 RESEARCH DESIGN

The research in this thesis is guided by the design research methodology (DRM) developed and described by Blessing and Chakrabarti (2009). The DRM supports design research to contribute to knowledge useful for design practice. Moreover, the DRM supports researchers to explain what is researched and not, which helps to base future research on prior research. DRM was therefore considered to be a suitable overall method to apply.

Blessing and Chakrabarti (2009) describe the following two objectives for design research:

- ...the formulation and validation of models and theories about the phenomenon of design with all its facets (people, product, knowledge/methods/tools, organisation, micro-economy and macroeconomy); and
- the development and validation of support founded on these models and theories, in order to improve design practice, including education, and its outcomes.

The first part is about developing an *understanding* of design, the second is about developing *support* for design (Blessing and Chakrabarti, 2009). This licentiate thesis focuses on the first part, the *understanding* of design.

The framework of the DRM, its four stages, and the stages to which the research questions in this thesis apply, are described in Figure 2.

The first stage, *Research Clarification*, concerns setting the basis for further research. Literature and empirical data may be collected, mainly for the purpose of an improved plan for the next step. In this thesis, the *Research Clarification* stage contributed with answers to RQ2.

Figure 2 The framework of the Design Research Methodology (DRM), based on Blessing and Chakrabarti (2009). The *Research Clarification* stage contributes with answers to RQ2. The *Descriptive Study I* stage contributes with answers to RQ1, RQ2 and RQ3.

The second stage, *Descriptive Study I*, concerns describing a situation so that it can be well understood. The research conducted in this stage contributed with answers to RQ1 and 3, and additional answers to RQ2.

The third stage, *Prescriptive Study*, concerns developing design support for improving the situation described in the second stage (*Descriptive Study I*). The fourth stage, *Descriptive Study 2*, concerns evaluating design support, for example design support developed in the third stage (*Prescriptive Study*), and bases the evaluation on the understanding of the situation acquired from the second stage (*Descriptive Study I*). The *Prescriptive Study* and *Descriptive Study 2* are not included in the research in this thesis.

To fulfil the aim of this thesis, a literature study and a multiple case study of two international, listed, business-to-business manufacturing companies in Sweden were conducted. In the multiple case study, empirical data was collected using semi-structured interviews with two employees at each company and by analyzing the companies' latest sustainability reports.

The relation between the research questions, stages in the Design Research Methodology (DRM), the main data collection methods and appended papers is described in Table 1.

Table 1 Relation between research questions, stages in the Design Research Methodology (DRM), appended papers and main data collection methods.

Research Questions	Research Clarification	Descriptive Study I	
	Paper II	Paper I	Paper III
		Multiple Case Study	
RQ1: How do manufacturing companies include sustainability aspects in their product development?	-	Semi-structured interviews; and analyzing sustainability reports	-
RQ2: Which challenges do manufacturing companies face when including sustainability aspects in their product development?	Literature study	-	Semi-structured interviews
RQ3: Why do manufacturing companies face challenges when including sustainability aspects in product development?	-	-	Semi-structured interviews

The following chapters motivate the selection of a multiple case study and a literature study methodology and describe how the multiple case study, semi-structured interviews, analysis of sustainability reports, literature study and comparison of data have been performed.

2.2 LITERATURE STUDY

A literature study is a method that helps the researcher to identify existing knowledge on the research area of interest (Bell and Bryman, 2007). A literature study is also one of the methods suggested by Blessing and Chakrabarti (2009) for the *Research Clarification* stage. During the *Research Clarification* stage, the research in this thesis focused solely on environmental aspects. Therefore, a literature study was conducted to reveal challenges and trends within *ecodesign* (Paper II).

For Paper II, literature was searched in Science Direct⁶ by using the Boolean search word combination: eco-design AND (“product development” OR “product design” OR “engineering design”) AND (method OR tool). Additional papers were identified by recommendations from Science Direct own pop up function and by tracking down references in selected papers. Science Direct was used because earlier work by a colleague indicated that Science Direct included relatively much literature about ecodesign and similar approaches, when compared to Scopus, Emerald Insight⁷ and Business Source Premier⁸.

The identification of *challenges* in the literature reviewed included the following terms: *challenges*, *barriers*, *problems*, *needs* and *calls for improvement*. The term *challenges* was collectively used for all these words. The challenges identified in the literature study contribute answers to RQ2 and complement the answers from the semi-structured interviews.

The framework in Table 2 was used to categorize the challenges as it enabled analysis of the challenges from different perspectives.

Table 2 The framework used for categorizing challenges and trends in Paper I. Adapted from Byggeth and Hochschorner (2006).

Category	Description
System and success level	Describes what is to be sustained, which is the “ <i>human society with the surrounding ecosystems</i> ” (Byggeth and Hochschorner, 2006), and principles of how to successfully achieve that.
Strategy level	The strategies applied in an organization, that guide what to invest. Investments shall give enough economic return on investment and at the same time contribute to sustaining human society and the surrounding ecosystems, described in the “System and success level”
Action Level	The actual activities done, and decisions taken, when working in line with the strategies applied in the “Strategy level”.
Methods level	The methods applied that support the activities done and decisions taken in the “Action level”.

The framework is a modified version of the “*system level model*” applied by Byggeth and Hochschorner (2006), and which originates from the work by Robért

⁶ www.sciencedirect.com

⁷ www.emeraldinsight.com

⁸ www.ebsco.com/products/research-databases/business-source-premier

(2000). To better fit the purpose of the literature study, the *systems* and *success levels* used by Byggeth and Hochschorner (2006), were merged, see the second row *system and success level* in Table 2.

The quality of the literature study in Paper II was mainly achieved by describing how the literature was searched and selected, and by describing how the authors have interpreted the data in the studied literature.

2.3 MULTIPLE CASE STUDY

A multiple case study methodology inspired by Yin (2014) was applied. In this thesis the multiple case study consists of two cases. According to Yin (2014) a case study methodology is suitable when the research questions are of the type “why”, or “how”, focus on contemporary events and do not require control of behaviors of the events. The focus of the research described in this thesis is on contemporary events, and the idea was to catch the answers to the research questions during the interviews without having control of any other event at the companies. Additionally, RQ1 and RQ3 are “how” and “why” questions, respectively. Therefore, a case study methodology was found suitable for answering RQ1 and RQ3. One important idea with the research in this thesis was to understand the reasons for the challenges identified by RQ2. Due to the logic relation between RQ2 and RQ3, it was decided to use a case study methodology also for answer RQ2, even though RQ2 starts with the word *which*. A multiple case study provides the possibility to describe each (individual) case and at the same time allows for comparison between the cases (Bryman and Bell, 2007). For these reasons, a multiple case study methodology was selected.

An idea the author had that contributed to the choice of a multiple case study methodology, was to describe real-life examples of how manufacturing companies work, and which challenges the manufacturing companies face, when including sustainability aspects in their product development. These real-life examples, i.e. the cases, are intended to represent a context for general theories and prescriptive research. According to Flyvbjerg (2006), case studies can provide such contextual knowledge.

Yin (2014) states that it is important to clarify the units of analysis used in the case study prior to data collection. The units of analysis for this multiple case study are:

1. The process of inclusion of sustainability aspects in product development
2. The sustainability aspects focused on
3. The actors involved when sustainability aspects are included in product development
4. The goals the manufacturing companies for the inclusion of sustainability aspects in product development
5. The methods applied when including sustainability aspects in product development
6. The challenges the companies face when including sustainability aspects in product development
7. Who (which actor) faces each challenge the companies face when including sustainability aspects in product development
8. The reasons why the companies face challenges when including sustainability aspects in product development

In a case study it is important to make sure data is linked to the purpose of the study; one way of doing that is to compare cases and aggregate findings from the comparison (Yin, 2014). Because the purpose of this study was to expand current knowledge on the inclusion of sustainability aspects in product development at manufacturing companies, the two cases were compared with each other as well as with prior research by other researchers. The comparison of *challenges* (number 6 in the list above), and *reasons why the companies face challenges* (number 8 in the list above) are further described in subchapter 2.3.5 Comparison of challenges and reasons for challenges.

Construct validity, internal validity, external validity and reliability are criteria that can be used to assess the quality of research. Construct validity concerns making sure the measures used are relevant for the study. Internal validity concerns establishing a strong causal relationship between variables (only applicable for explanatory studies). External validity concerns describing the settings in which the findings from the study can be generalized. Reliability concerns clearly describing how the study was conducted. Several *strategies* (see Table 3) can be applied to achieve high construct validity, internal validity, external validity and reliability. (Yin, 2014)

Table 3 summarizes how construct validity, internal validity, external validity and reliability have been established in this thesis.

Table 3 Suggested and applied strategies for achieving high research quality of a case study. The two left columns are based on Yin (2014) and the right column describes the strategies applied in this thesis.

Criteria to strive for	Suggested strategy to apply	Strategy applied in this thesis
High construct validity (Is the measured variable relevant for the study?)	Use multiple sources of evidence	Two (interview) respondents with different roles and one document (the sustainability report) were selected as sources of data. Respondents selected were expected to contribute with trustworthy data.
	Establish chain of evidence	Mainly established by describing the relations between (1) research questions and interview questions, and (2) data and conclusions.
	Have key informants review draft case study report	All respondents reviewed, adjusted and verified the case descriptions.
High internal validity (establish causal relationships)	Do pattern matching	Analyzing which of the identified reasons for challenges that are most common. Being transparent on how the data has been interpreted.
	Do explanation building	-
	Address rival explanations	Methodological implications of the findings of reasons for the challenges are discussed.
	Use logic models	-
High external validity (generalizability)	Use theory in single-case studies	-
	Use replication logic in multiple-case studies	Cases that are representative for a group, but expected to have several differences, were chosen (theoretical replication). Additionally, analytic generalization has been applied.
High reliability (describe how the study was conducted)	Use case study protocol	Research questions, names and roles of contact persons, detailed data collection practices and the relation between (1) interview questions, (2) research questions and (3) questions regarding the company context was created, used and stored in computer files.
	Develop case study database	Raw data and drafts of the case study were stored in dedicated software (NVivo) and in computer files.

Construct validity is achieved by using three sources of data at each manufacturing company; by describing the relation between research questions, interview questions, data and conclusions; and by letting the respondents verify and adjust the case descriptions. In addition to the strategies to achieve high construct validity suggested by Yin (2014), high validity (here interpreted as high construct validity)

can be established by selecting trustworthy sources of data (Maxwell, 2012). Therefore, interview respondents were selected carefully.

In this thesis, internal validity concerns the validity of the causal relationship between challenges faced by the companies and the reasons why they face these challenges, i.e., the idea behind RQ3. Internal validity is mainly achieved by:

1. Discussing how the methodology applied has affected what reasons for challenges that are found. This is here interpreted as what Yin (2014) describes as “*addressing rival explanations*”.
2. Letting the respondents verify the case descriptions, which includes the respondents’ own explanations of reasons for the challenges. Such verification increases internal validity according to Lincoln and Guba (1985;1994) as referred to by Bryman and Bell (2007). However, Bryman and Bell (2007) question whether respondents should validate the analysis of the empirical data. Therefore, no analyses or findings were verified by the respondents. Only the case descriptions, which mainly include empirical data compiled as case descriptions, were verified by the respondents. Note: Yin (2014) classifies this as achieving construct validity.
3. Analyzing which reasons for challenges are the most common, which is here interpreted as what Yin (2014) describes as “*pattern matching*”.
4. Being transparent on how the data has been interpreted.

External validity is achieved by analytic generalization and theoretical replication. Analytic generalization means that a theory or hypothesis (which applies on a higher level than a single case) is tested. The test may result in “...*corroborating, modifying, rejecting, or otherwise advancing theoretical concepts [theories or hypotheses]*...”, or that new theories or hypotheses are developed (Yin, 2014). For a multiple case study, theoretical replications means to select cases that are expected to contribute contrasting results (Yin, 2014). Analytic generalization has mainly been performed by comparing the empirical data in the multiple case study with descriptions in studies by other researchers on how manufacturing companies include sustainability aspects in product development, which challenges they face, and the reasons for the challenges. The descriptions in prior research compared with serve as pieces of the current knowledge base, i.e., the theory. The comparison between empirical data and the theory is depicted in Figure 3. Case studies can be used for both generating and testing a theory (Bryman and Bell, 2007). In this thesis, the comparison is a means of testing and developing the theory. Theoretical replication was performed by selecting companies of the same type (representative

for a group), but which still had many differences, and were expected to give contrasting results.

The multiple case study in this research	Comparison	Descriptions in prior research, which represent the theory that is being compared
How do the <i>case companies</i> include sustainability aspects in their product development?	↔	How do <i>manufacturing</i> companies include sustainability aspects in their product development?
Which challenges do the <i>case companies</i> face when including sustainability aspects in their product development?	↔	Which challenges do <i>manufacturing</i> companies face when including sustainability aspects in their product development?
Why do the <i>case companies</i> face the identified challenges?	↔	Why do <i>manufacturing</i> companies face challenges when including sustainability aspects in product development?

Figure 3 The analytic generalization was conducted by comparing the empirical data in the multiple case study with descriptions in prior research, where the descriptions in prior research represent the theory.

According to Yin (2014), one of the strategies to achieve high reliability is to create and use a case study protocol. A case study protocol is a short and clear description of the most important information that is needed to perform the research. In the research for this thesis, the case information considered most relevant included research questions, names and roles of contact persons, detailed data collection practices and the logic between interview questions, research questions and questions regarding the company context. This case information was stored in computer files. The relation between interview questions, research questions and questions regarding the company context, shown in Appendix D, is considered to be an important part of the case protocol because its development supported the creation of a relevant set of interview questions.

Maxwell (2012) argues the researcher shall identify the “*most serious and plausible*” threats to validity, and suitable strategies for dealing with these threats. In this research, the most important threat to validity was considered to be bias from the author when interpreting the interviews and the case descriptions. That threat has been managed by letting the respondents verify the case descriptions, and by

describing how the author has interpreted and aggregated data from the case descriptions.

2.3.1 IDENTIFICATION OF THE THEORY COMPARED WITH

The theory compared with in the multiple case study was covered by literature describing *how* manufacturing companies include sustainability aspects in product development, the *challenges* they face when including sustainability aspects in product development, and the reasons *why* they face these challenges.

Literature describing *how* manufacturing companies include sustainability aspects in product development was mainly searched in Science Direct and Web Of Science⁹ using the Boolean search word combination: (sustainab* OR ecodesign OR eco-design) AND practice AND (“product development” OR “product design”) AND (empiric* OR case-stud* OR “case stud” OR interview*), where “*” represents a wildcard. Web of Science was selected as a source of literature due its good reputation by colleagues. Science Direct was selected, as described in subchapter 2.2. Literature study, due to earlier work by a colleague that indicated that Science Direct included relatively much literature about ecodesign and similar approaches.

Literature describing *challenges* that manufacturing companies can face when including sustainability aspects in product development was mainly search in Science Direct using the Boolean search word combination: (challenge OR barrier OR hinder) AND (ecodesign OR “eco-design” OR DFE OR “sustainable product development” OR “sustainable product design” OR “sustainable design”).

Literature describing reasons *why* the manufacturing companies face challenges when including sustainability aspects in product development was covered mainly by the same literature that describe challenges manufacturing companies can face when including sustainability aspects in product development. Boolean search word combinations, which included words such as: ecodesign, reasons, why, cause, challenges, sustainable product development, were tested. The search engine “Unisearch” (available at the library of Linköping University) was the main search engine used. “Unisearch” covers many databases, for example, Science Direct, Scopus and Web of Science. However, no specific literature that focuses on describing reasons *why* manufacturing companies can face challenges when including sustainability aspects in product development, was identified. Instead,

⁹ www.webofknowledge.com

the tests resulted mainly in the same literature identified when searching for *challenges*. In the literature of *challenges*, the reasons for challenges and barriers were occasionally described. Those occasionally described reasons for challenges and barriers serve as the main part of the theory of reasons *why* manufacturing companies can face challenges when including sustainability aspects in product development.

Additional literature (relating to *how*, *challenges* and reasons *why*) was identified by: (1) tracking down references in the identified literature (snowballing); (2) suggestions from research peers; (3) recommendations from the author's network in Researchgate¹⁰, (4) testing search words combinations in 'Unisearch' and (5) screening literature already identified in the literature study (subchapter 2.2. Literature study).

Literature was search prior to, and during, the multiple case study.

2.3.2 SELECTION OF CASE STUDY COMPANIES

Manufacturing companies that include sustainability aspects in product development, and which try to improve that inclusion, were searched for. Such companies were expected to contribute with novel data, and to serve as real-life examples of how sustainability aspects can be included in product development. Companies' efforts to improve were expected to reveal data about which challenges manufacturing companies can face when including sustainability aspects in their product development. Within this "group" of companies, the idea was to study companies which could contribute with contrasting data, i.e., companies that work differently and face different challenges. Therefore, companies that developed different type of products were searched for.

The search for suitable manufacturing companies for interview was conducted by studying externally communicated information on the web pages of:

1. manufacturing companies of which the author of this thesis already had some general knowledge
2. manufacturing companies of which the co-author of the appended papers knew through a network.

For practical reasons, manufacturing companies with a product development site in Sweden were selected.

¹⁰ www.researchgate.net/

Thirteen manufacturing companies were contacted and invited to participate in the case study. All thirteen manufacturing companies had communicated on their publicly available web pages that they include environmental aspects, sometimes referred to as sustainability aspects, in their product development. Six of the thirteen manufacturing companies agreed to participate, and semi-structured interviews were conducted at all six companies. Due to time limitations, two of the companies were selected for further analysis and inclusion in the multiple case study.

The two companies selected for the multiple case study, Companies A and B, described practices related to health and safety, and responsibility in their supply chains. The impression was that the two companies had thought about what sustainability means for them. However, when studying the sustainability reports and reading the web pages, the impression was that Company B communicated its contribution and commitment to sustainability more than Company A. Both companies used a structured and documented *product development process*¹¹. The two companies develop different type of products and are active in different business areas. The research in this thesis covers parts of the product portfolio of each company. For Company A, products from one of its business areas are covered while for Company B, its main type of product is covered. This thesis focuses on the physical parts of both companies' products. Both companies are international, listed, business-to-business, companies that develop, manufacture and sell products. Company A's products consist mainly of mechanical components, electronic components and service. Company B's products are mainly mechanical; however, electronics and control functions are included as well. Service is also provided by Company B. Differences between Companies A and B and their products are clarified in Table 4.

Table 4 Main differences between Companies A and B

Company A's products are more complex than the products of Company B.	
The products developed by Company A include more electronics and service than the products by Company B.	
Company A has more than 12,000 employees.	Company B has more than 10,000 employees.

¹¹ "the sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product" (Ulrich and Eppinger, 2008).

2.3.3 SEMI-STRUCTURED INTERVIEWS

Semi-structured interviews are one of the two methods applied in the multiple case study for collecting empirical data (the other is analysis of sustainability reports).

Semi-structured interviews are recommended if the interviewer has a “*fairly clear focus*” on what to investigate and how to analyze the data but wants to be able to “*pick up on things*” said by the respondent. Multiple case studies may require some structure to ensure comparability. Semi-structured interviews can provide that structure. (Bryman and Bell, 2007)

Therefore, semi-structured interviews were considered to be a suitable data collection method. The semi-structured interviews performed contribute with answers to all research questions (RQ1, 2 and 3). In addition, the semi-structured interviews contribute with data that serves as context to the answers, such as what sustainability means for the companies and what are the main drivers for the companies to include sustainability in product develop.

The interview questions were generated prior to the interviews. To ensure that the interview questions would generate answers relevant for the research questions, all interview questions were mapped against RQ1 and RQ2. Follow-up questions relating to RQ3 were mapped against RQ2, since RQ3 depends on RQ2. The interview questions can be seen in Appendix D.

Prior to the semi-structured interviews, each invited company received a description of the purpose and the main topics of the interview. Each of the six companies interviewed was asked to select suitable interviewees (one or more), based on the author’s requirement for covering the main topics of the interview after *all* interviews at each company had been conducted. At three companies, two interviews were conducted at each company. At the other three companies, one interview was conducted at each company. In total, nine semi-structured interviews were conducted. All interviews were fully transcribed. At the two manufacturing companies selected for inclusion in the multiple case study (Companies A and B), two interviews were conducted at each company. The respondents selected by the companies are shown in Table 5.

Before the interviews at the selected manufacturing companies, the interview questions were tested on a colleague with experience from working with inclusion of environmental aspects in product development at a manufacturing company.

Table 5 Presentation of the respondents at the two case companies, Company A and Company B. RA1 means Respondent 1 at Company A, adapted from Paulson and Sundin (2018) (Paper III).

Respondent and his/her role	Experience of Respondent
RA1: Head of environmental management	Worked with environmental issues for 20 years in various positions at Company A
RA2: Project environmental coordinator	Worked with inclusion of environmental aspects in product development projects at Company A for 3 years
RB1: Coordinator of environment, safety, and health ¹²	Worked with environment and work environment for 29 years. Worked 15 years at Company B, 8 of those also with sustainability
RB2: Manager of the main product development department	2 years in current position. 18 years' experience working as a design engineer and project manager in product development at Company B

The interview questions were prioritized to make sure the most important questions would be answered during the interview, in case of lack of time. The interviews were clocked, so that the interviewer (the author of this thesis) knew when each prioritized interview question had to be asked. Each interview was voice recorded and took between 90 and 110 minutes.

All interviewees had access to paper and pencil during the interview so that they could visually describe things, in addition to verbal descriptions. In addition to voice recordings at Company B, the paper was video recorded during the two interviews, which enabled listening to what the interviewee said while writing and sketching on the paper. Company A did not allow video recordings at the place where the interviews were conducted.

All interviews were fully transcribed and summarized in two case descriptions, one for Paper III (based on RQ2 and RQ3), and one for Paper I (based on RQ1). Each case description was reviewed and followed by a 30-40 minute telephone discussion with each respondent, during which, among others, follow-up questions relating to interesting topics or unclear answers were asked. All respondents had

¹² The purpose of *environment, safety and health* can be described as "... *prevent and reduce accidents, emergencies, and health issues at work, along with any environmental damage that could result from work practices*" (safeopedia, n.d.).

the opportunity to adjust and make a final verification of the case descriptions. Importantly, the case descriptions also included data collected from the sustainability reports. That means that the respondents reviewed data also from the sustainability reports. The interview questions are described in Appendix D.

2.3.4 ANALYSIS OF SUSTAINABILITY REPORTS

A document is one of six common sources of data in case studies. A document can be valuable in a case study because it can be reviewed several times, can include detailed information and is not a result of the case study. However, documents are biased towards the author of the document. (Yin, 2014)

A sustainability report is a company's public report "... *about the economic, environmental and social impacts caused by its everyday activities*" (globalreporting.org, n.d.). This content was considered suitable to include in the multiple case study. The sustainability reports were expected to contribute with data that complements and gives context to the interviews. For these reasons, the companies' latest sustainability report (from year 2015) was selected as a source of data. The interview questions, Appendix D, were used as the base for what data to search for, for example, "*On which sustainability-related aspects does your company focus its efforts?*"

Quality of the analysis of sustainability reports is mainly achieved by being restrictive in the interpretation of the data in the sustainability reports.

2.3.5 COMPARISON OF CHALLENGES AND REASONS FOR CHALLENGES

To increase current knowledge on challenges that manufacturing companies can face when including sustainability aspects in product development, the completeness of the framework of challenges for ecodesign implementation by Dekoninck et al. (2016) (see Appendix A) was tested and updates proposed.

In addition, to increase current knowledge on reasons for challenges that manufacturing companies can face when including sustainability aspects in product development, current knowledge on reasons for this type of challenges was tested and updates proposed.

In this thesis, comparison of challenges and reasons for challenges are the practical means for these "tests".

When comparing challenges and reasons for challenges, the challenges were classified as either *same*, *similar*, *have similarities* or "-" if no similarity could be found, see Figure 4.

Figure 4 Relation between terms used when comparing challenges and reasons for challenges.

Same means that the description of two challenges, or the description of a challenge and a reason for a challenge, have some words in their title that are considered to mean the same thing. Additionally, the two challenges, or a challenge and a reason for a challenge are considered the *same* if “*the challenges are considered [by the author] to mean the same thing; ... if they describe things in the same level of detail; and ... how easily one of the challenges can be interpreted as meaning something else [such interpretation shall not be easily made]*” (Paper III). Note: classifying as *same* implies tolerating some, but minor, differences between the two objects compared.

Have similarities means that two challenges, or a challenge and a reason for a challenge, can be interpreted to mean the same thing while, at the same time, can easily be interpreted to *not* mean the same thing. Additionally, *have similarities* is used when two challenges, or a challenge and a reason for a challenge, are described in different levels of detail. *Similar* is a classification between *same* and *have similarities*.

The testing and proposed updates to the framework of Dekoninck et al. (2016) were undertaken according to the following process:

1. Comparing the challenges at Companies A and B and classifying them as *same*, *similar*, *have similarities*, or “-”.
2. Comparing the challenges at Companies A and B with challenges and barriers identified in prior research and classifying them as *same*, *similar*, *have similarities*, or “-”.
3. Identifying challenges at Companies A and B that are at least *similar* (between each other), and which are not clearly described in the framework of Dekoninck et al. (2016), i.e., which are only classified as *have similarities*, or “-” in the comparison with Companies A and B. Additionally, identifying a challenge or barrier in prior research that is at least *similar* to the challenges at Companies A and B. At least three *similar* challenges are now identified, each from a separate source.
4. The three challenges identified in the third step are rephrased into one single challenge that keeps the meaning of the three original challenges. The

rephrased version is proposed added to an updated version of the framework of Dekoninck et al. (2016).

The reason for having three sources (step 3) is that the relevance of the suggested challenge is considered to be higher if identified in three sources rather than in one or two.

The reasons for challenges identified at Companies A and B and challenges and barriers described in prior research by other researchers were compared according to the same process as described above, with one difference; it was the *reasons* for challenges at Companies A and B that were compared with challenges and barriers found in other research.

3 FRAME OF REFERENCE

This chapter describes the concepts of sustainability, sustainable development, product development, ecodesign and sustainable product development. Additionally, this chapter includes descriptions from prior studies on how manufacturing companies include sustainability aspects in their product development, which challenges the companies face when doing so, and reasons for the challenges.

3.1 SUSTAINABILITY AND SUSTAINABLE DEVELOPMENT

Sustainability is in this thesis defined as a target situation in which humanity on earth lives in a way that can be sustained. It is however acknowledged that it is not yet agreed upon what to *sustain* in sustainability (see Sala, 2013).

The term *sustainable development* was coined by The World Commission on Environment and Development (WCED, 1987), and is a widely used definition of sustainable development. The definition states:

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- the concept of ‘needs’, in particular the essential needs of the world’s poor, to which overriding priority should be given; and
- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs. (WCED, 1987)

To make the definition of sustainable development more useful for business people, in 1994 John Elkington coined the term *Triple Bottom Line* (TBL) (Elkington, 2004). The TBL explains what a company has to consider, do, and account for, to sustain and also contribute to sustainability (Elkington, 1999). The three lines are economic prosperity, social justice and environmental quality. Between these lines there are shear zones, for example business ethics, which is located in the shear zone between economic prosperity and social justice (Elkington, 1999). For sustainable development, the quality of the environment represents the ultimate bottom line on which the economy depends, and the society depends on the

economy (Elkington, 1999), see the picture on the left in Figure 5 below. Alternative visual descriptions of the TBL have been developed, see, e.g., the picture on the right in Figure 5, in which sustainability is defined as “... *simultaneously achieve environmental, economic and social sustainability*” (Wu, 2013). One difference between the pictures is that the left picture shows priority between the bottom lines (environmental bottom line has highest priority, social bottom line has least priority), the right picture does not. In addition to companies, the TBL is used by many nonprofit organizations and is now increasingly adopted by U.S. governments at state, regional and local levels (Slaper et al., 2011).

Figure 5 Left: The Triple Bottom (TBL) lines, based on Elkington (1999). Right: The TBL, adapted from descriptions by Wu (2013).

The TBL can be seen as a practical definition of sustainability (Rogers and Hudson, 2011). Concrete examples of use of the TBL include sustainability reporting by companies (Global Reporting Initiative, n.d.), and by the United Nations when the 17 global development goals were created for the sustainable development agenda for year 2030 (United Nations, 2015). A common and alternative description of the TBL is *people, planet and profit* (the 3Ps) (Slaper et al., 2011). The 3Ps was coined in 1995, and John Elkington also contributed to the development of this term (Elkington, 2004).

Two additional definitions, or perspectives, of sustainable development are *strong* and *weak sustainability*, see Figure 6. The main difference between *strong* and *weak sustainability* concerns the use of natural capital, such as fish stocks and fresh, non-polluted air and water. In *weak sustainability* the total capital, which can be described as (1) the natural capital (e.g., iron and fish), (2) capital that mankind has produced (e.g., cars and infrastructure), (3) human capital (e.g., people’s knowledge and experience) and (4) social capital (e.g., culture), must not decrease

in the long-term. However, in *weak sustainability*, trade-offs between these types of capital can be made, which means that a reduction in the natural capital can be considered a sustainable strategy if other capital increases correspondingly, such as improved infrastructure (Gulliksson and Holmgren, 2015). In *strong sustainability* the stock of natural capital must not decline, which implies that mankind must only consume what the earth can produce (Gulliksson and Holmgren, 2015). An additional explanation given by Wu (2013) is: “*strong sustainability means that economic activities are part of the social domain, and both economy and society are constrained by the environment [the natural capital]*”. Consequently, trading the fish stocks with improved infrastructure becomes problematic in *strong sustainability*.

Figure 6 Visual description of *weak* and *strong sustainability* (Wu, 2013).

There are many different interpretations of sustainability among researchers. Moreover, the terms *sustainability* and *sustainable development* are mostly viewed as synonymous (Wu, 2013), for example, in the work by Elkington (1999).

3.1.1 SUSTAINABILITY FOR A COMPANY

According to Elkington (1999) and Elkington (2004), the business conditions in the world change in a direction that requires businesses that want to survive to change focus; not only to consider the economic value they create but also to consider the social and environmental value they create or destroy, i.e., companies need to account for their TBL. Therefore, the TBL is henceforth used as a framework when describing what sustainability may be for a company.

Economic sustainability for a business can be described as the business' ability to sustain into the future. However, in order to sustain, the business has to understand how its activities affect the environment and people, and how the impact on the environment and people affect the economic risk of the business (Doane and

MacGillivray, 2001). Björklund (2012) describes a similar definition: *“The economic sustainability, from a business perspective, can be considered good if its long-term economy is secured”* (translation by the author of this thesis). Björklund further states that some companies interpret economic sustainability as profit. Finally, Hallstedt (2017) describes economic sustainability as part of a company’s risk and value perspective, including *“e.g., innovation potentials, increased competitiveness, energizing employees, cost, profit, and investments”*.

Social sustainability for a company relates to the company’s interaction with society and people. Some examples are: the company’s activities targeting good employee health, safety in the workplace, employee education, product quality, customer service, and safety and health for the customer (Björklund, 2012).

Environmental sustainability is described by Gulliksson and Holmgren (2015, translation by the author) as, for example: protection of biodiversity, *“maintain the capacity for production of water, soil and ecosystems”*, or *“the impact on the health of the environment and people is limited to what the ecosystems can manage or recover from”*. There are additional definitions of environmental sustainability, but as yet no consensus (Gulliksson and Holmgren (2015).

No specific business-related definition of environmental sustainability is found in the literature covered in this thesis. However, environmental sustainability is reflected in the work many companies do to minimize the environmental impact of their activities. Björklund (2012) and Ammenberg (2012) mention, for example: (1) working according to the corporate environmental management standard ISO 14001, (2) using environmental product labelling (to show that the product complies with certain standards), and (3) sustainability reporting according to the Global Reporting Initiative’s standards (Global Reporting Initiative, n.d).

From a company perspective, environmental, social and economic sustainability are not equally important. Elkington (1999) and Carrol (1991) state that the economy is the ultimate bottom line for a company. Similarly, Tischner and Charter (2001) state that sustainable businesses must meet the same financial requirements *“as any other business in the private sector”* (as referred to in Paper I).

According to Byggeth & Hochschorner (2006) *“it is unlikely that a company will make a choice that is not primarily economically driven. ... Therefore, there is a risk that the environment will not be the highest priority in some trade-off situations”*. Several additional researchers have made similar findings, for example Björklund (2012), Deutz et al. (2013), Ammenberg (2012) and Short et al. (2012).

3.1.2 SUSTAINABILITY ASPECTS OF MANUFACTURED PRODUCTS

A sustainability aspect is here defined as any aspect that affects the possibility to reach a situation in which humanity on earth lives in a manner that can be maintained. But, what is a sustainability aspect of a manufactured product?

There are few concrete examples in prior research that describe what a *sustainability aspect*, or *environmental*, *social* and *economic aspect*, is. Instead, other terms are used for which concrete examples are given. Such terms are, for example, *socio-ecological criteria* (Hallstedt, 2017), *product sustainability index* (Shuaib et al. (2014), *sustainability indicators* (Joung et al., 2012). These terms are in this thesis interpreted as sustainability aspects, which gives rise to the following examples.

Examples of environmental aspects of manufactured products are: emissions, pollution, natural habitat conservation, consumption of water, consumption of material, consumption of energy, land use (Joung et al., 2012); compliance with regulation and certifications related to the use of material, End-Of-Life strategy (e.g., landfill and recycling) (Shuaib et al., 2014); energy efficiency during the use phase and “*select non-toxic and harmless resources*” (Issa et al., 2015).

Examples of social aspects of manufactured products are: well-being of (1) employees (covering health and safety, professional development and satisfaction with the company); (2) customers (covering health and safety impacts on customers from the manufacturing and use of the product, satisfaction and rights of customers); and (3) community (covering for example engagement in development programs for the community, human rights, equity and corruption) (Joung et al., 2012); no forced labor, no child labor, no corruption (Ekener, 2013; Gould et al., 2017), access to improved drinking water, freedom of association, gender equity and access to basic knowledge (Gould et al., 2017); product quality and durability, functional performance, product End-Of-Life management, product safety and health impact, and that the product complies with End-Of-Life regulations and certifications (Shuaib et al., 2014).

The term “*socio-ecological sustainability criteria*” used by Hallstedt (2017) is a merger of environmental and social aspects. Examples of socio-ecological sustainability criteria for products are “*no usage of conflict minerals for product components and/or its production*”, and “*no usage of materials that contain or result in chemicals that are included in the REACH-candidate list*” (Hallstedt, 2017).

Economic aspects of manufactured products and processes can be described as growth, broken down into profit, cost and investments made by the company (Joung et al., 2012). Hallstedt (2017) adds innovation potential, increased competitiveness and energizing employees. For a company to be interested in an investment, the time it takes to get return from the investment needs to be short enough (Byggeth and Hochschorner, 2006) Rodrigues et al. (2016) include conventional financial KPIs in profit, which here is interpreted as including short-term profit. Shuaib et al. (2014) describe: (1) costs of initial investment, such as capital and costs for Research and Development (R&D), (2) direct and indirect costs, such as cost of labor and material, and (3) benefits of market value and loss of quality. Economic aspects are important, since without positive business drivers, one shall not expect industry to integrate environmental aspects in their product development (Tukker et al, 2001; Byggeth and Hochschorner, 2006).

3.2 PRODUCT DEVELOPMENT

Product development can be defined as *“a set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product”* (Ulrich and Eppinger (2008). When to do the activities can be described in the product development process, which has been defined as *“the sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product”* (Ulrich and Eppinger, 2008).

There are various ways of thinking about a product development process; for example, as a system that manages risks. In this system, risks related to assure that *“... the product will work correctly and be well received by the market”* are identified and prioritized in early phases of the product development process, and addressed in the process' subsequent steps. (Ulrich and Eppinger, 2008)

There are several attempts in the literature to visually, and in text, describe a product development process, for example by Ullman (2010), Ulrich and Eppinger (2008) and Cooper (2008). According to Ulrich and Eppinger (2008), product development processes described in literature are simplified descriptions of the activities a company may conduct when developing a product. The actual product development processes employed differ between companies and between product development projects, due to the unique context of each company and project (Ulrich and Eppinger, 2008). Despite many process descriptions in the literature describe a linear work flow, the actual work conducted may include loops within and between the stages (Cooper, 2008). Therefore, the product development

process referred to in this thesis (Figure 7) shall be seen as a simplified example of a product development process.

Figure 7 An overall description of the product development process, adapted from Ulrich and Eppinger (2008).

Each stage includes many activities. Some of the activities are described below.

During the planning phase it is prioritized which product development projects, from a portfolio of project ideas, to run. Examples of activities conducted in the planning phase are: identifying business opportunities, identifying “...*the portfolio of products to be developed by the organization and the timing of their introduction to the market*” and allocating resources for product development projects. Additionally, for each selected product development project, sales arguments, target markets, assumptions, constraints and what the new product shall do, are described. There are additional names for the activities conducted in the planning phase, e.g., product planning and product management. (Ulrich and Eppinger, 2008)

During *concept development*, customer needs are identified, “*product concepts are generated*”, the concepts are evaluated and “... *one or more concepts are selected for further development* ...” (Ulrich and Eppinger, 2008).

In the *system-level design* phase, the selected concept/concepts is/are analyzed from an architectural viewpoint. Suitable subsystems and components are defined. Deliverables from the system-level design phase may include, for example, a specification of each subsystem’s function. (Ulrich and Eppinger, 2008)

During *detail design*, the geometry of the product, the materials to be used, the tolerances required and a plan for how to manufacture components are defined.

Deliverables from the detail design phase are, for example, geometrical descriptions of each component (e.g., drawings) and an overall plan for how the product shall be manufactured. (Ulrich and Eppinger, 2008)

The *testing and refinement* phase includes, for example, design, manufacturing and evaluation of product prototypes (Ulrich and Eppinger, 2008).

During the *production ramp-up* phase manufacture of the product commences. The aim of this phase is to identify problems in the manufacturing system and to train the personnel working in production. After this phase the product is launched to the market. (Ulrich and Eppinger, 2008)

According to Ulrich and Eppinger (2008), developing good, successful products is hard. There are many methods available to support the product development work. Examples of methods are: Computer Aided Design (CAD) and technical models that simulate the behaviour of a product (Ullman, 2010; Ulrich and Eppinger, 2008).

3.2.1 DEVELOPMENT OF PRODUCT REQUIREMENTS

A *product requirement* is a statement that describes “... *in precise, measurable detail what the product has to do*” (adapted from Ulrich and Eppinger, 2008). Well performed identification of customer needs, and translation of the needs into product requirements, are key to being able to develop products that are well received by the market and give return on investment. These customer needs can be called *aspects*. An *aspect* “...*implies 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). That means, in the context of this thesis, that any need, issue, problem etc. can be seen as an aspect as long as it has not yet been processed into a product requirement.

Prioritizing product requirements is important (Ullman, 2010), as is ensuring that product requirements are formulated in a way that describes *what* to do, without telling *how* that shall be done (Ulrich and Eppinger, 2008).

Product requirements can be developed in a requirements development process (Nilsson, 2017). Ulrich and Eppinger (2008) describes the requirements development process concisely as: Firstly, customer needs are identified. Secondly, the customer needs are translated into a set of measurable metrics, which constitute an early set of product requirements. The early set of product requirements guides development of the product concept. Thirdly, a final set of product requirements are decided upon after the most promising concept is selected.

3.2.2 ACTORS INVOLVED IN PRODUCT DEVELOPMENT

Many actors can be involved in product development. What type of product is developed, is one factor that determines which and how many actors are involved. A product is commonly developed by a team, which consists of actors with different responsibilities. The team can be viewed as consisting of a core team and an extended team. The core team may consist of a marketing professional, industrial *designer*¹³, mechanical designer, electronics designer, purchasing specialist and manufacturing engineer. An extended team may consist of suppliers, people working with legal issues, finance and sales personnel. (Ulrich and Eppinger, 2008).

An additional actor that may be included in the core or extended team is the *products owner*. A *product owner* is responsible for the economic success of a product, or a portfolio of products (adapted from Robertson & Robertson, 2013). The term *product owner* occurs in the agile software development literature (e.g., Gustavsson, 2007) and in literature describing how requirements can be developed efficiently (e.g., Robertson and Robertson, 2013). Other terms sometimes used as synonyms with *product owner* are *product manager* (romanpichler.com, n.d.), and *project owner* (Gustavsson, 2007). The *product owner* has an influence on what products shall be developed and what needs a new product shall fulfil. For example, Haines (2013) argues that the product manager (here interpreted as synonymous with *product owner*) “... describes the functional and non-functional characteristics of the product that reflect customer and business needs”.

3.2.3 ECODESIGN

Products are designed and manufactured to fulfil needs, for example, customers' needs. However, as mentioned in the introduction of this thesis, the consumption of products has an impact on, for example, the environment. Ecodesign is an approach that can be applied by manufacturing companies to reduce the environmental impact of their products (Norrblom et al., 2000) and it can be defined as “*integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycle*” (ISO 14006:2011). *Integration* is here interpreted as synonymous with *inclusion* and means that someone is actively thinking of a certain aspect when planning for, or doing, a task.

¹³ A *designer* is here “a person who plans the look or workings of something prior to it being made, by preparing drawings or plans” (en.oxforddictionaries.com, n.d.)

Much research has been conducted within ecodesign, which took off in the early 90s. In the beginning ecodesign focused on the company, the product and environmental aspects and has evolved to a widened scope that includes additional actors in the value chain (e.g., the suppliers), systems thinking and sustainability. (Boks and McAloone, 2009)

An *ecodesign method* has been defined as “any systematic means for dealing with environmental issues during the product development process” (Baumann et al., 2002), and “any specific procedure with a specified desired outcome that could be performed in a product development process in order to support the work towards an environmental goal” (Ekermann and Lindahl, 2013). Many ecodesign methods have been developed and new ecodesign methods keeps being developed (Pigosso et al. (2015)). However, according to Pigosso et al. (2015), between 2006 and 2010 ecodesign methods were not necessarily applied in industry. A number of ecodesign methods are listed by Lindahl and Ekermann (2013), Rousseaux et al. (2017), Bovea and Pérez-Belis, (2012), and Rossi et al. (2016). For example: quantitative analytical methods, such as Life Cycle Assessment (LCA); qualitative analytical methods, such as the Materials, Energy, Toxic emissions (MET) matrix (Brezet and van Hemel, 1997, as referred to by Bovea and Pérez-Belis, 2012); checklists, such as the EcoDesign Checklist (Brezet and van Hemel, 1997) and Volvo’s lists of banned and restricted substances (referred to by Rousseaux et al., 2017); guidelines, such as the Ten Golden Rules (Luttropp and Lagerstedt, 2006); Quality Function Deployment (QFD)-based methods, such as QFDE (Masui et al., 2003); CAD integrated methods, such as SolidWorks Sustainability (SolidWorks, 2018); and Failure Mode Effect Analysis-based methods, such as Environmental Effect Analysis (EEA) (Lindahl et al., 2000).

3.2.4 SUSTAINABLE PRODUCT DEVELOPMENT AND DESIGN

According to Tischner and Charter (2001), sustainable product development and design has been described as product development in which economic, social and environmental aspects are balanced, i.e., taking into consideration the *triple bottom lines* when developing products and services. Compared to ecodesign, the scope of sustainable product development and design is wider and includes social and ethical aspects in addition to environmental aspects (Tischner and Charter, 2001).

More radical views of sustainable product development can also be found. According to Roy (1997), sustainable product development aims at developing products for a sustainable society, in which it is important to meet *essential* human needs rather than *any* need, or desire, for a product. Roy (1997) further argues that sustainable product development requires radical thinking rather than minimizing

the environmental impact of a product. Consequently, sustainable product development may even question the need for a product, when comparing the need for a certain product with its impact on sustainability (Roy, 1997). Similar thoughts were brought up even earlier by van Weenen (1995).

Hallstedt (2008) describes sustainable product development as “*product development with a full systems perspective on socio-ecological sustainability*”, which is in line with how Roy (1997) defines sustainable product development.

3.3 PRIOR RESEARCH RELATED TO THE RESEARCH QUESTIONS

This subchapter describes how other researchers in prior studies describe how manufacturing companies include sustainability aspects in their product development, which challenges the manufacturing companies face when doing so and what are the causes of the challenges.

3.3.1 INCLUSION OF SUSTAINABILITY ASPECTS IN PRODUCT DEVELOPMENT

Examples of how manufacturing companies include environmental aspects in their product development is described by Polikidou et al. (2014); Tingström et al. (2006); Deutz et al. (2013); Stevels (2007); Ölundh and Ritzén (2004); Jönbrink et al. (2013); Sihvonen and Partanen (2016). An example of the inclusion of social aspects in product development at a manufacturing company is described by Mesquita (2016) and an example of the inclusion of sustainability aspects at a manufacturing company is described by Hallstedt and Thompson (2011).

According to Ölundh and Ritzén (2004), at the large vehicle manufacturer Scania, sustainability is included in the company's product strategies. The authors further describe that at Scania, there are departments within the product development organization, and each of the departments has an environmental coordinator, who belongs to a group organized by an environmental coordinator higher up in the organizational hierarchy. Environmental aspects are systematically included in the preparation and evaluation of project ideas. The project manager is a central actor for the inclusion of environmental aspects in the final specification (interpreted by the author of this thesis as the final product specification). Environmental performance is one of the technical parameters that are used when evaluating project ideas. Scania's ambition is that all product specifications shall include clear

demands and targets (interpreted by the author of this thesis as *environmental requirements*¹⁴). (Ölundh and Ritzén, 2004)

At two, of in total “*four vehicle manufacturing companies in Sweden*”, described in the multiple case study by Poulíkidou et al. (2014), “*environmental specialists [here interpreted as a person with knowledge about the environment and society’s impact on the environment] are systematically assigned during the different stages of product development*”, and “*environmental requirements are included in the same documents with other design requirements*” At one of the companies, the company’s “*environmental specialists*” monitor “*regulation and market needs*” from a central position, rather than in the product development projects. Activities to create a formalized process for the inclusion of environmental aspects in product development are ongoing at three of the companies. The companies apply methods during product development which support the reduction of the environmental impact of their products. Some of the methods are systematically applied in all four companies, some in a few companies, see Table 6 (next page) for the methods systematically and not systematically, applied. Poulíkidou et al. (2014)

Poulíkidou et al (2014) further describe that the use of benchmarking indicators and customer surveys support setting environmental goals for future products and are applied already in the planning phase. Economic risk and opportunities are important drivers and are sometimes the “*actual ‘enablers’*” for the inclusion of environmental aspects in product development. Examples of environmental aspects considered are: reducing the energy consumption from the vehicle’s use phase and, phasing out hazardous substances from the companies’ products. (Poulíkidou et al., 2014)

Several examples of how manufacturing companies in Sweden include environmental aspects in their product development are described by Jönbrink et al. (2013). Jönbrink et al. (2013) found that large manufacturing companies often include the environmental requirements that are considered most important in their product development process. They also found that most manufacturing companies that include sustainability aspects in product development assign the responsibility of that inclusion to a person responsible for environmental aspects, rather than to

¹⁴ a necessary condition that when fulfilled is considered to reduce the environmental impact.

Table 6 Methods applied according to the respondents at the companies studied by Poulidikou et al. (2014). Grey fields represent methods that are systematically applied at the companies.

Type and name of method	Company 1	Company 2	Company 3	Company 4
<i>Mapping and generation ideas (product planning)</i>				
Brainstorming	X			X
Mind mapping				X
Customer surveys	X			
Benchmarking indicators	X	X	X	X
<i>Guidelines and checklists (product development and design)</i>				
Environmental design guidelines	X	X	X	X
Recyclability checklists (DfR)	X		X	
Substance and chemical control lists	X	X	X	X
<i>Performance indicators (product development and design)</i>				
Environmental Priorities strategy indices	X	X		
Recyclability indicators	X	X		X
Eco-footprint	X			X
Vehicle performance indicators	X	X	X	X
<i>Databases (product design)</i>				
Material database systems	X	X	X	X
<i>Tools for impact assessment (product development and detailed design, complete product)</i>				
Life Cycle Assessment (LCA)/Simplified LCA	X	X	X	X
Environmental Impact Assessment/Environmental Failure Mode Effect Analysis (E-FMEA)	X	X		
Life Cycle Cost analysis (LCC)	X			X
<i>Communication methods (complete product)</i>				
Environmental Product Declaration (EPD)	X			X
Testing and verification (product development, complete product)				
Simulations/laboratory testing	X	X	X	X

all employees active in the product development project. In many of the companies, the marketing function is active in the inclusion of sustainability aspects in product

development. Several manufacturing companies have environmental requirements for their products; however, employees often lack education and methods. Life Cycle Assessment (LCA) is conducted at several of the large manufacturing companies. The companies often focus on a few sustainability aspects, rather than applying a holistic perspective. The sustainability aspects focused on are the ones that show synergies between economy and sustainability. A few of the companies studied include sustainability aspects in their companies' strategies, goals and operations. Purchasers are mentioned as an actor that affects what requirements the purchased goods shall fulfil. (Jönbrink et al., 2013)

To understand to what extent environmental aspects are included in product development and which environmental aspects the designers think are relevant for their products, Deutz et al. (2013) studied small, medium and large manufacturing companies with a product development site in the UK. Deutz et al. (2013) conducted a questionnaire, to which 93 companies responded, and semi-structured interviews at nine manufacturing companies. Environmental aspects included in the concept development stage were mainly applied to select a concept rather than to generate new concepts. Deutz et al. (2013) found that the early phases (before detailed design) of the product development process was not well performed. For example, environmental requirements are mostly formulated as *“design parameters”* (interpreted by the author of this thesis as requirements focusing on *how* the solution shall be fulfilled) rather than as *“functional requirements”*, which focus on *what* the solution shall do. Additionally, Deutz et al., (2013) found that *“there are companies that are aware of environmental concerns relating to their products, but do not consider them in design, and there are companies taking environmental issues into account in design without being aware of their environmental implications”*.

How the consumer electronics section of the Dutch manufacturing company Philips includes environmental aspects in product development is described by Stevels (2007) as:

At Philips Consumer Electronics this [inclusion of environmental aspects in the product development process] has been done by a simple ‘add on model’. For each activity an ‘environmental paragraph’ has been added to existing procedures. In this way all the basic processes (like strategy, product creation, purchasing production, marketing and communication) became environmental.

Further, according to Stevels (2007), several methods for including environmental aspects in product development have been applied at Philips Consumer Electronics. For example, the Eco-indicator 95 and Eco-indicator 99 methods, Environmental

benchmarking, EcoDesign Matrix (covers economic, environmental and social aspects), STRETCH and lists with banned and restricted substances. Table 7 illustrates important environmental aspects focused on by Philips Consumer Electronics.

Table 7 Environmental aspects that Philips Consumer Electronics focus on, based on Stevels (2007)

Environmental aspect	Environmental effect
Energy reduction	Less emissions
Material reduction	Less resources
Transport and packaging	Less emissions and resources
Substances reduction	Less emissions
Durability and recyclability	Less resources

Studying the work by Stevels (2007), Philips appears to consider also social aspects when developing new products. Additionally, Stevels (2007) shows an example of how Philips has the ability to analyze which environmental aspects are aligned with earning money, and it is these environmental aspects that Philips focuses on.

In a survey studying how environmental aspects are considered in product development at Finnish manufacturing companies, Sihvonen and Partanen (2016) found that the majority of the companies studied had an “*environmental policy*”, an “*environmental objective*” and had “*environmental requirements for suppliers*”. Additionally, the functional requirements in use in the companies studied did not frequently include environmental considerations.

According to a survey in 2003 of Japanese and South Korean international electronic industries, a “*lack of environmental goals and vision for individual development projects*” is one of the main obstacles for “*successfully bringing ecodesign products to the market*” (Boks, 2006).

So far, environmental aspects have been the focus in the studies described. The examples below describe how *social aspects*, and more generally, *sustainability aspects*, are included in product development.

Mesquita et al. (2016) studied the inclusion of social aspects in product development at an aeroengine manufacturing company in Sweden and found that consideration of social aspects are present at the company, but are mainly directed to: health and safety aspects in their own company, “*development of a code of conduct*”, “*...an employee satisfactory survey*”, “*a sustainability report at the corporate level including some social aspects*”, and “*development of social- and*

environmental requirements on suppliers". Among the interviewees there was no clear understanding of what social aspects of sustainability are, and what these aspects mean in concrete tasks in their daily activities.

The manufacturing company ABB includes sustainability in its product development and uses a stage gate product development model where sustainability aspects are considered already in (or even before) the planning phase (Tingström et al., 2006). The process at ABB, described by Tingström et al. (2006) is summarized as:

1. "... *Identify sustainability requirements*", from e.g. laws, "*regulations, customer demands, risks [and] hazardous materials.*"
2. "*Conduct ...[an] environmental assessment for the current type of product*" by performing a "*screening LCA*" or applying some "*qualitative environmental assessment*" method.
3. "*Set sustainability goals based on the significant sustainability aspects and establish a sustainability action plan about how to achieve these goals.*"
4. "*Communicate the sustainability plan to the project members and other relevant stakeholders.*"
5. "*Implement the actions in the sustainability plan.*"
6. "*Follow up to determine whether the sustainability plan fulfilled the objectives and document the results.*"

Furthermore, ABB applies mandatory and customized checklists when developing its products. The checklists are used systematically and cover aspects such as: content of conflict minerals in the product; improvement of energy efficiency in the entire value chain; and health and safety aspects related to the product. The checklists are the main and key method applied for including sustainability aspects in product development at ABB. (from a conversation with, and presentation by, Lennart Swanström, ABB, during an academic course, May, 2017)

An aeroengine manufacturer in Sweden, studied by Hallstedt and Thompson (2011), applies methods that support consideration of sustainability aspects in product development. The most frequently applied methods are: "*Environmental Impact Assessment (EIA), material lists [here interpreted as lists with banned and restricted substances] and guidelines for suppliers [here interpreted as overall requirements for suppliers]*". Additionally, the company has a method for evaluating suppliers from an environmental perspective. Decisions related to making the product more sustainable are taken mainly in the concept development phase. However, an actual effect from the EIA comes later and has thereby less

effect on the selection of concepts and design than intended. The actors with the highest responsibility for inclusion of sustainability aspects in a product development project are the project manager and the project steering committee. Purchasers have knowledge about environmental aspects of manufacturing processes and social aspects, such as working conditions, at suppliers. The aeroengine manufacturer has concrete targets on reduction of noise, high reliability, low weight and reduced emissions. Among engineers, reduction of fuel consumption is considered the most important sustainability aspect. Environmental managers have a wider scope, which includes both environmental and social aspects. Additional aspects considered are alternative fuels and smarter flight routes. (Hallstedt and Thompson, 2011)

3.3.2 CHALLENGES AND BARRIERS

Manufacturing companies can face challenges and barriers when including environmental aspects in product development. The terms used include *challenges*, *barriers*, *problems*, *hurdles*, *hinders* and *obstacles*, where, in this thesis, *problems*, *hurdles*, *hinders* and *obstacles* are interpreted as synonymous with *barriers*.

Examples of empirical studies on barriers, obstacles, hurdles or hinders, are: Jönbrink et al. (2013), van Hemel and Cramer (2002), Poulidikidou et al. (2014), Boks (2006), Short et al. (2012), Bey et al. (2013). Empirical studies of challenges are: Mesquita et al. (2016), Hallstedt and Thompson (2011), Schulte and Hallstedt (2017), Danjelico and Pujari (2010) and Dekoninck et al. (2016). However, Dekoninck et al. (2016) treat challenges as synonymous with barriers, hurdles and obstacles. Similarly, challenges, problems and barriers are treated as synonyms by Schulte and Hallstedt (2017a).

Most of these studies focus on challenges and barriers that relate to the inclusion of *environmental* aspects in product development. The study by Mesquita et al. (2016) focuses on *social* aspects.

Economic aspects have not been studied separately in the literature covered in this thesis, whereas environmental and social aspects have. However, economic aspects have been included nonetheless, in at least some of the studies listed above. For example in a survey, answered by engineering companies in Sweden, “*economy*” was the main barrier for considering “*sustainability*” when developing the companies’ products (Jönbrink et al., 2013). Additionally, about 7% of the respondents in the study by Bey et al. (2013) mentioned cost-related barriers, such as (the need to) meeting economic targets.

Interestingly, several of the interviewed respondents in the study by Jönbrink et al. (2013) argued that there is no barrier to including environmental aspects in product development. However, one of the respondents in the study by Jönbrink et al. (2013) clarifies and states: “*as long as it does not cost more [money] than they [the company] earn*” (translation by the author).

In addition to the collection and analysis of empirical data, Dekoninck et al. (2016) made a literature study on challenges that manufacturing companies face when “... *implementing ecodesign ...*”. The result from their literature study and analysis of the empirical data is presented in a framework, which, according to Dekoninck et al. (2016), supports cross-case analyses and identification of new challenges, and consolidates the research on challenges that can be faced by manufacturing companies when implementing ecodesign. The framework of Dekoninck et al. (2016) is presented in Appendix A in this thesis.

In the same year as Dekoninck et al. (2016), Stewart et al. (2016) published a literature study of “... *barriers to implementing different types of sustainability approaches*” in companies. The result by Stewart et al. (2016) is based on 29 empirical studies; one important finding is that external barriers, such as “*multiple [,] complex [and] changing regulation*” and “*lack of industry-specific information*”, can efficiently hamper considerations of sustainability issues in a company. Additionally, Stewart et al. (2016) classified the identified barriers into internal and external barriers and described them in two frameworks.

To enhance the application of methods that can support the inclusion of (mostly) environmental aspects in product development, there is research studying barriers to the application of these methods and/or how to address these barriers. For example, see Lindahl (2005), Rossi et al. (2016), Prendeville et al. (2011) and Knight and Jenkins (2009).

Examples of challenges and barriers identified in prior empirical studies by other researchers are presented in Appendix C.

3.3.3 REASONS FOR CHALLENGES AND BARRIERS

If manufacturing companies are to be able to address the challenges they face when including sustainability aspects in product development, it is important to understand what is causing the challenges. This subchapter describes prior research by other researchers in which a causal relationship between a challenge or barrier, and the “something” that is causing the challenge or barrier, has been expressed. This “something” is the “reason” for the challenge or barrier.

Frequently mentioned reasons for challenges to include sustainability aspects in product development, identified by Schulte and Hallstedt (2017a), are:

- “... *the relation between sustainability and profitability is not obvious ...*”
- “... *product cost might get higher and it is unclear if all customers are willing to pay extra for a more sustainable product*”
- a risk of “... *higher investment costs*” in the short term
- there might be “... *a perceived risk of decreased profitability*” in the short term.

According to Poulidikidou et al. (2014), the intention of the “... *processes, responsibilities, information flows, available documentation ...*” and methods used at four vehicle manufacturers in Sweden, is to support the inclusion of environmental aspects in product development. However, the utilization of these processes, responsibilities etc., is inefficient and the reasons include:

- time constraints,
- the large size of the organization
- high complexity of the product

Since Poulidikidou et al. (2014) studied barriers, not challenges, one could see the three “reasons” as reasons for barriers.

Reasons for the challenge to include social aspects in product development at a manufacturing company in Sweden are identified by Mesquita (2016). The reasons are:

- thinking of social aspects is not included in the responsibilities of the company’s employees
- social aspects are “... *interpreted mainly as health and safety ...*” aspects, within their own company
- social aspects are not “... *translated into concrete tasks and guidelines ...*” that are needed for developing a product.

Product development in general is challenging (Ulrich and Eppinger, 2008). It is challenging with or without the inclusion of sustainability aspects. Some of the “*characteristics*” pointed out by Ulrich and Eppinger (2008) that make product development challenging are:

- it is difficult to recognize, understand and manage the trade-offs that have to be made, and do that *"in a way that maximizes the success of the product"*
- it is difficult to make decisions in a work environment that is constantly changing; for example, customer preferences change over time
- the large number of decisions that have to be made in product development; for example, on the details of the design
- time pressure, which makes the characteristics in the earlier points even more challenging
- getting a *"reasonable return on investment"*, from the development of a product.

These *"characteristics"* are by the author of this thesis interpreted as reasons that make product development challenging.

As mentioned in the former subchapter 3.3.2 Challenges and barriers, there are barriers (Jönbrink et al., 2013; van Hemel and Cramer, 2002; Poulikidou et al., 2014; Bey et al., 2013), obstacles (Boks, 2006), hurdles and hinders (Short et al., 2012) described in prior studies, which can hamper the inclusion of sustainability aspects in product development. These barriers, obstacles, hurdles and hinders may also be seen as reasons for challenges related to the inclusion of sustainability aspects in product development. However, that is not explicitly expressed in their studies.

4 SUSTAINABILITY ASPECTS IN PRODUCT DEVELOPMENT

This chapter is dedicated to answering RQ1 (How do manufacturing companies include sustainability aspects in their product development?) and does so by analysing and discussing findings from the multiple case study on how Companies A and B include sustainability aspects in their product development. The findings relate mainly to: the perspective on sustainability, the companies' product development processes, sustainability aspects, actors involved, goals and methods applied.

4.1 THE PERSPECTIVE OF SUSTAINABILITY

The case study indicates that Companies A and B apply a weak sustainability perspective. Additionally, the economy is the ultimate bottom line for Companies A and B. All this is in line with how Elkington (1999) and Carroll (1991) describe sustainability for a company. For example, at Company A functional requirements are in general prioritized higher than environmental requirements in cases where a solution that meets both environmental and functional requirements is not found. The implication is that environmental impact can be traded with improved functionality, i.e., a characteristic of weak sustainability. At Company B, developing and selling a low energy efficient product can be prioritized higher than developing and selling a higher energy efficient product. This can happen if the low energy efficient product is considered to be the most efficient product development initiative to fulfil the economic goals of Company B; see also challenge number 6 at company B (CB6) in Paper II. The number of products sold can affect the total environmental impact (Ammenberg, 2012). However, the number of products sold is not mentioned by either Company A or B, which strengthens the idea that the companies apply a weak sustainability perspective.

The strong sustainability perspective, and the TBL perspective by Elkington (1999), derived from sustainable development (WCED, 1987), in which the environmental bottom line forms the base, are not identified at Companies A and B.

4.2 PROCESS

This subchapter describes findings relating to the process of including sustainability aspects in product development at manufacturing companies.

4.2.1 SYSTEMATIC INCLUSION

The case study strongly indicates that there are companies that systematically include sustainability aspects in their standard product development process, i.e., there is no separate process for the sustainability aspects. However, the aspects manufacturing companies focus on may differ, as well as how they include the sustainability aspects. The following seven points are examples of activities and roles at Companies A and B which are interpreted by the author as evidence for a systematic inclusion of sustainability aspects in product development at Companies A and B.

- Company A has a role called *Project Environmental Coordinator*, who works in product development projects to include environmental aspects and requirements.
- Company A phases out and substitutes hazardous substances in a strategic manner, in which manufacturing and material specialists come up with and prepare prespecified solutions for phasing out and substituting hazardous substances, which designers can select in the product development project.
- At Company A, all product development projects must describe how they will manage environmental aspects.
- Company A uses mandatory checklists and Company B uses checklists at and before gates to incorporate sustainability requirements into the product development project.
- Company B systematically conduct *Environment, Safety and Health* reviews of the product during its development, with emphasis at the gate between concept development and the detailed design phase.
- At Company B the person responsible for *Environment, Safety and Health* at the company must approve the product concept before the detailed design phase can start.

There are differences in *how* Companies A and B include sustainability aspects in their product development; for example, Company A has *Project Environmental Coordinators* while Company B does not. Additionally, Company B has made several LCAs in the past, which showed that the use phase represents more than 95% of their (main) product's environmental impact, as a result of energy consumption in the use phase. Due to alignment of cost reductions for Company

B's customers and the reduction of environmental impact, Company B focuses on increasing the degree of energy efficiency in the use phase of their products. The interpretation by the author is that Company B applies, to some degree, a life cycle perspective. Company A does *not* apply a life cycle perspective when developing their products, at least not consciously.

When comparing Companies A and B with other manufacturing companies described in other research, similarities are found. For instance, the large manufacturing company ABB systematically use checklists (conversation with, and presentation by, Lennart Swanström, ABB, during an academic course in May 2017) and sets “...*sustainability goals based on the significant sustainability aspects...*” (Tingström et al., 2006) in their product development projects. Companies A and B also systematically use checklists. Additionally, ABB uses LCA to focus on important sustainability aspects, as does Company B. The four large vehicle manufacturers studied by Poulíkidou et al. (2014) apply a life cycle perspective, in a similar way to Company B, and include environmental aspects in their standard product development processes, as do both Company A and B. Additionally, the four large vehicle manufacturers studied by Poulíkidou et al. (2014) systematically use “*substance and chemical control lists*” and “*recyclability indicators*”. It is apparent that there are companies other than Companies A and B which systematically include sustainability aspects in product development, but in different ways. Systematic inclusion of sustainability aspects in companies' ordinary product development processes is therefore not a new phenomenon, and Companies A and B come under this group of companies.

4.2.2 WHEN AND HOW SUSTAINABILITY ASPECTS ARE INCLUDED

The case study shows that the phase of the product development process in which sustainability aspects are included varies between manufacturing companies. The inclusion of sustainability aspects may start in the planning phase, for example, as done by Company A, the four vehicle manufacturers studied by Poulíkidou et al. (2014), one manufacturing company studied by Hallstedt et al. (2013) and ABB, studied by Tingström et al. (2006). In contrast, the inclusion of sustainability aspects may start later, for example, in the concept development phase, as done at Company B and at the manufacturing companies studied by Hallstedt et al. (2013), at which “*decisions regarding major sustainability implications are made mainly in the concept phase...*”. Inclusion of sustainability aspect can be done even later, as identified at manufacturing companies studied by Deutz et al. (2013). However, manufacturing companies are not necessarily satisfied with the timing of the inclusion of sustainability aspects in their product development. For example, both

Companies A and B want to include sustainability aspects much earlier in the product development process than they currently do.

At Companies A and B, marketing and sales are the main actors for eliciting customer needs. However, marketing and sales do not systematically search for sustainability aspects that are important for their current and potential customers, which may result in missed sustainability-related business opportunities. For example, at Company A customer needs are not thoroughly scrutinized, which indicates that Company A does not actively search for customers' underlying needs (that are related to sustainability) in the planning phase of their product development process. Neither Poulikidou et al. (2014) nor Tingström et al. (2006) describe *how* the elicitation of sustainability aspects is conducted at the vehicle manufacturers and ABB, respectively, but this would be interesting to know. In general, there is a lack of empirical studies describing how, and how commonly sustainability aspects (e.g., sustainability-related customer needs) are elicited from customers by, for example, marketing and sales. It would however be interesting to read a study that describes how manufacturing companies that are considered "best in class" elicit sustainability aspects from customers. Such a study was not found during the search for literature in this thesis.

The case study shows that Company A lacks inclusion of sustainability aspects when eliciting customer needs in the planning phase, and Company B lacks inclusion of sustainability aspects in the beginning or before the concept development phase and in the planning phase (see Paper I). However, is it that simple? The case study shows that sustainability aspects enter the planning phase of the product development process also from internal goals and knowledge developed in prior projects.

For example, at Company B, the knowledge gained from the LCAs conducted more than ten years ago, and the internal goals: (1) *"the degree of energy efficiency of sold products on average shall be increased by 1%"*; and (2) *"the percentage of sales from new products that are launched in the past five years shall increase and reach 25% by the year 2020"* (Paper I), is used in the planning phase. The knowledge gained from the LCAs conducted has clearly influenced the formulation of the goals. Moreover, the knowledge gained from the LCAs and the goals affect the product requirements and the selection of product development projects to run. At Company A, the goal that *"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"* in the EU

(RoHS:2011) (Paper I) is intended to affect the inclusion of sustainability aspects in product development (including the early phases of product development).

The case study clearly gives two different results. One where there is a lack of sustainability aspects included in the planning phase of the product development projects (when eliciting customer needs), and one where sustainability aspects are included in the planning phase (from internal goals and prior developed knowledge). The different answers are most probably the result of different perspectives on the scope of a product development project. A novel finding from this thesis is therefore; descriptions of when and how sustainability aspects are included in product development depend on the scope of the product development process that is included in the study. Studying a specific product development project without its relation to prior projects and *Research and Development* (the development and use of scientific knowledge, ending with the outcome of physical products, Trott, 2008) activities, will most probably give different results to a study that includes such relations.

Additionally, the case study does not indicate that prior projects, in which, for example, LCAs are conducted and knowledge useful for the product development projects is developed, must be *product development projects*. Instead they could be some other type of project.

An important comment is that just because sustainability aspects, such as sustainability-related customer needs, are identified does not mean those sustainability aspects will be prioritized at a manufacturing company. Other needs may be more important for a customer. However, if these sustainability aspects are not even identified there is little chance they will be prioritized and included in the product requirements.

The main findings can be summarized as: the case study shows that inclusion of sustainability aspects in the planning phase of the product development project is lacking; however, sustainability aspects can enter the planning phase in other ways, e.g., from internal goals and prior developed knowledge. Descriptions of when and how sustainability aspects are included in product development therefore depend on the scope of the product development process that is included in the study. Marketing and sales do not systematically search for sustainability aspects that are important for their current and potential customers.

4.3 SUSTAINABILITY ASPECTS

This subchapter describes findings relating to manufacturing companies' views on what is a sustainability aspect, and how these aspects are included in product development.

4.3.1 WHAT IS SEEN AS A SUSTAINABILITY ASPECT?

Sustainability aspects are by Companies A and B mainly referred to as environmental and social aspects. Economic aspects are mainly referred to as profit, or return on investment, and serve as a prerequisite for any initiative at the companies. The three "lines" of sustainability aspects are therefore not equally prioritized; instead, economic aspects are the basis for decisions. This is in line with Elkington (1999) and Carrol (1991) who state that the economy is the ultimate bottom line for a company.

Environmental aspects are mainly referred to as phasing out hazardous substances from products and production (Company A) and reducing energy consumption from the products' use phase (Company B). Both companies consider additional environmental aspects when developing their products; however, those environmental aspects seem to be of lesser importance to communicate. For example, Company A works with extending the use phase of its products by making the products easy to maintain, and Company B phases out hazardous substances from its products too. The four environmental categories described by Joung et al. (2012), emission, pollution, resource consumption and natural habitat conservation, cover the environmental aspects described by Companies A and B well. The main environmental aspects described by Companies A and B, i.e., the use of hazardous substances and the energy consumption, are among the environmental aspects described by Shuaib et al. (2014), Issa et al. (2015) and Poulidikidou et al. (2014). Additionally, the use of hazardous substances is described as an important environmental aspect in a product development project at ABB (Tingström et al., 2006). The case study thereby indicates that *phasing out hazardous substances* and *reduce energy consumption from products' use phase* are relevant environmental aspects for industry.

Social aspects mainly refer to health and safety in the companies' own workplaces, and health and safety, no forced labor, no child labor in the supply chain. Similarly, occupational health and safety are important aspects considered in product development at ABB (Tingström et al., 2006). An interesting perspective by respondents at Companies A and B was that social aspects, such as health and safety, no forced labor and no child labor, are not easily applicable in design.

Instead, the respondents thought that managing and taking decisions on these social aspects are primarily the responsibility of the purchasing function. A similar perspective is reported by Mesquita et al. (2016), which strengthens the idea that social aspects are, by manufacturing companies in Sweden, mainly seen as working conditions in the supply chain. However, this is of course a perspective that can be changed in the future. The assumed relatively low occurrence of child labor and forced labor at workplaces in Sweden may explain why child labor and forced labor seem to be considered mainly for the supply chain.

Safety aspects for the user of the companies' products are described by the respondents as *product safety* (Company B) or *system safety* (Company A) and do not seem to be associated, nor even *need* to be associated, with social aspects or sustainability aspects at all. Product and system safety are simply product and system safety, nothing else. It is interesting that Joung et al. (2012) and Shuaib et al. (2014) classify product safety as a social aspect. This implies that one cannot argue that designers and systems safety engineers at Companies A and B, who work in product development and affect product safety, do not consider social aspects since that depends what is interpreted as a social aspect.

Schulte and Hallstedt (2017a) identified confusion as to what social sustainability means and how social aspects shall be identified in the product developing manufacturing companies they studied. The results of the research described in this thesis corroborate the findings of Schulte and Hallstedt (2017a) in that there is no clear common view on what a social aspect is. Evidence includes the differing views between the case companies and the prior studies by Joung et al. (2013) and Shuaib et al. (2014) on whether product safety is a social aspect. The case study however contrasts with the finding by Schulte and Hallstedt (2017a) in that Companies A and B do not seem to be confused about what social aspects are; they have their own view of social aspects and use that view.

Economic aspects are mainly viewed as profit, or return on investment. Profit and return on investment are in line with the economic aspects *profit* and *investments* (investment relates to return on investment) described by Joung et al. (2012), the *short-term profit* mentioned by Rodrigues et al. (2016), and the *return on investment* described by Byggeth and Hochschorner (2006). The findings do not falsify *cost*, *market value* and *loss of quality* as economic aspects (Shuaib et al., 2014 described these as economic aspects). However, neither do the findings strengthen them as economic aspects. For instance, cost is mentioned by both companies, but the case study does not find cost most important. The finding that profit and return on investment is more important than cost is in line with Jönbrink

and Melin (2008), who found that increasing customer value is more important than cutting costs. Perhaps because cost is just *one* of the things that affect profit and return on investment; revenues do too.

Business ethical aspects, such as *no corruption*, are not clearly defined as an economic, social or environmental aspect at Companies A and B (but classified as a social aspect by Joung et al., 2012). Instead, Companies A and B describe *no corruption* as part of their efforts to govern their businesses in a responsible manner. Clearly, classifying sustainability efforts into the dimensions of the triple bottom line is not always done at Companies A and B, and Companies A and B do not force the introduction of such classification in product development. They do not seem to think it is relevant to do that. The unclear classification of business ethical aspects at Companies A and B is also described by Björklund (2012). The novel findings from the case study is that in practice, business ethical aspects are not clearly categorized into the triple bottom lines. Additionally, no obvious need for categorizing business ethical aspects into the triple bottom lines, from a practical point of view in manufacturing companies, is identified.

To summarize the main findings: at the case companies, sustainability aspects mainly refer to environmental and social aspects; economic aspects mainly refer to profit or return on investment. Economic aspects serve as a prerequisite for any initiative. The case study indicates that *phasing out hazardous substances* and *reduce energy consumption from product's use phase* are relevant environmental aspects for industry. The case study strengthens the idea that social aspects are mainly seen by manufacturing companies in Sweden as working conditions in the supply chain. Whether designers, or system safety engineers, consider social aspects depends on what is defined as a social aspect. No obvious practical need has been identified at the case companies for categorizing business ethical aspects into the triple bottom lines.

4.3.2 ECONOMY IS A PREREQUISITE FOR INCLUSION OF ANY ASPECT

At Companies A and B, profit and return on investment are prerequisites (and thereby part of the key) for the inclusion of any aspect, for example, environmental, social or business ethical aspects. Complying with legislation is here considered included in profit and return on investment, since without complying with mandatory legislation the possibility of conducting business in that region where the legislation is effective disappears, which is also clarified by Company A. Economic aspects (here mainly profit and return on investment) are therefore not on the same level as environmental and social aspects; economic aspects are the base. These findings are well in line with findings and statements by Elkington

(1999), Carroll (1991), Byggeth and Hochschorner (2006), Tischner and Charter (2001), Deutz et al. (2013), Ammenberg (2012) and Short et al. (2012).

Viewing economic aspects primarily as profit, or return on investment, serving as a prerequisite for implementing any initiative, may explain why sustainability aspects mainly refer to environmental and social aspects.

4.3.3 RISKS AND OPPORTUNITIES

The case study strongly indicates that Companies A and B focus on those sustainability aspects that reduce economic risk and create economic opportunities. For example, the risk of losing the supply of critical components and chemical products and material, mainly due to the EU regulation *Registration, Evaluation, Authorisation and Restriction of Chemicals* (REACH:2006), makes Company A to invest much effort to comply with REACH:2006 and to identify solutions that reduce the risk. The opportunity to sell products to countries with a specific legislation drives Company A to comply with that specific legislation. Company B is not covered by the Energy-Related Products directive in the EU, *Establishing a framework for the setting of ecodesign requirements for energy-related products* (ErP:2009). However, many customers do not know that and require Company B to comply with the ErP:2009 anyway. Therefore, despite Company B is not covered by the ErP:2009, it risks losing business if ErP:2009 is not complied with. At the same time, compliance with Erp:2009 generates opportunities to win business. The mentioned *risk* and *opportunity* drives Company B to develop products that comply with the ErP:2009. Clearly, identifying economic risks and opportunities is a matter of survival for a company.

The focus at the case companies on aspects that reduce economic risk and create economic opportunities is in line with findings by Poulikidou et al. (2014), who identified that “*business opportunities, economic incentives or business risks were ... reported [by vehicle manufacturers], as they were considered important drivers and along with regulation, the actual ‘enablers’ in some cases, for increasing the incorporation of [environmental] aspects during design decisions*”. Similarly, Danjelico and Pujari (2010) found that environmental regulation supports identifying new business *opportunities* and that complying with regulation supports the company to minimize *risks*, such as image protection. The focus on risk is in line also with the findings of Pascual and Boks (2004).

A risk can be turned into an opportunity. For example, at the companies studied by Schulte and Hallstedt (2018), “*threats [here interpreted as risks] and opportunities were described as two inseparable parts of the same coin, because mitigating*

threats also can constitute opportunities". This duality between risks and opportunities is similar to how the case companies view risks and opportunities.

Economic risks and opportunities can be viewed as drivers for the inclusion of sustainability aspects in product development. Tingström et al. (2006) discuss their findings, from their study of ABB, and believe that the reason for success of the way sustainability aspects were included in the specific product development project they studied was that reduced environmental impact, better work environment at ABB, reduced installation time, and reduced cost for the customer were aligned. Clearly, strong sales arguments for the product, and the whole product development project, were present, i.e., an economic opportunity. A similar situation is present at Company B, where reduced environmental impact from the products is aligned with economic savings for the customers. Because risks and opportunities can be viewed as two sides of the same coin, both economic risk and opportunities can be viewed as drivers for the inclusion of sustainability aspects in product development.

Both Companies A and B acknowledge the economic risks and opportunities associated with sustainability aspects. This could explain why sustainability aspects are included in the companies' standard product development processes. Notwithstanding, how important are the economic risks and opportunities associated with sustainability aspects for the companies? Could there be economic risks and opportunities related to *other* aspects, such as technological advancement (however, technological advancement is viewed as a sustainability aspect by Joung et al., 2012), which the company find more important for their survival and more efficiently fulfil economic goals? Yes, the case study strongly indicates that. For example, see challenge number 6 for Company B (CB6) in Paper III, in which a decision is taken by management to develop a product that is not in line with the ambition to reduce the environmental impact, but which better fulfils the economic goals of the company. This decision corroborates well the description of how businesses look at sustainability and economic sustainability, as described by Doane and MacGillivray, 2001). An additional reflection; companies make large investments in techniques enabling "Industry 4.0" (Price Waterhouse Coopers, 2016). One can argue that many of these companies do not invest in Industry 4.0 for the purpose of sustainability; however, win-win situations, for example, between reducing environmental impact and profit for the company, can of course be identified. Instead, the reason for investment is probably the opportunity to earn money, the risk of not being competitive in the future, and the risk of not surviving in the future competitive landscape.

Schulte and Hallstedt (2017b) discuss whether sustainability should be an *“objective in itself [for a company], side by side with other objectives for financial performance, quality etc.”* (Saardchom, 2013, as referred to by Schulte and Hallstedt, 2017b), or if sustainability shall be seen *“as a lens though which existing [or other] objectives are viewed”* (Faris et al., 2013, as referred to by Schulte and Hallstedt, 2017b), or if a combination of these two perspectives should be made. Schulte and Hallstedt (2017b) do not provide an answer but in an informative way shed light on the strengths and weaknesses of the perspectives and ask for research that, for example, describes how the combination of the two perspectives *“would work in practice”*. This thesis provides empirical data that contributes to this research gap. Companies A and B have goals for the inclusion of sustainability aspects in product development *“that are in line with sustaining and/or growing their business”* (Paper I). Additionally, the case study strongly indicates that economy (e.g., profit and return on investment), rather than sustainability, is the lens though which any aspect and initiative (including environmental and social aspects) are considered. This lens is a mirrored (and thereby contrasting) version of the perspective described by Faris et al. (2013), as referred to by Schulte and Hallstedt (2017b).

According to the author of this thesis, even investments in philanthropic activities, which both Companies A and B make, shall be seen through an economic lens, since the investment can pay off indirectly, for example, in society’s trust in the company and by increasing the employees’ networks (Company A) and good will (Company B).

Importantly, the profit and return on investment can be direct or indirect, and seen in a short- or long-term perspective. It depends on the time perspective of the investment. For example, Companies A and B want to be attractive employers. They believe that investing in attractive working conditions pays off (in some time perspective), since such investment attracts skillful people whom they can employ.

To summarize, the findings in this thesis strongly indicate that manufacturing companies focus on those sustainability aspects that are related to clear economic risks and opportunities. High economic risk (high in comparison with other economic risks identified) and great economic opportunity (great in comparison to other economic opportunities identified) are important means and drivers for reducing the environmental and social impact of products. Aspects other than sustainability aspects may be found to be more important for the economy (and perhaps even survival) of the manufacturing company. Moreover, economy is the

lens through which any aspect and initiative is considered, including sustainability-related aspects and initiatives.

4.3.4 THE EASE OF RELATING ASPECTS TO THE DESIGN OF THE PRODUCT

The findings from the case study strongly indicate that what matters is how clear the causal link between the design and any type of aspect is, if actors in the product development function, e.g. a designer, will find it relevant to consider the aspect.

For instance, currently, at the case companies, the causal link between a design decision (e.g., choice of material) and its impact on child labor, forced labor and health and safety in own and suppliers' workplaces, is unclear. Consequently, health and safety aspects at suppliers are difficult for designers to apply to their design. Instead, other actors, for which the causal link may be clearer, handle these types of aspects. For example, child labor, forced labor and health and safety at suppliers workplaces are mainly handled by purchasers. Efforts are made to make the causal link between the design and social aspects, such as forced labor and child labor, clearer, see e.g., Gould et al. (2017). The use of methods connecting design with such social aspects is however not yet mainstream.

In contrast, for product safety, the causal link to the design is clearer (product safety is described as a social aspect by Joung et al., 2012 and Shuaib et al., 2014). For example, the design of a chainsaw includes several mechanical solutions to avoid injuring the user in the event the chain breaks or the chainsaw kicks back during use. Actors within the product development functions at the case companies consider product safety (product/system safety engineers). However, as mentioned earlier, Companies A and B do not view product safety as a social aspect of their products. Additionally, energy consumption during the product's use phase (here seen as an environmental aspect), is by the author considered having a clear causal link to the design of the product. For example, at Company B, actors within the product development function make efforts to increase the degree of energy efficiency of Company B's products. Indeed, the clearness of the causal link between an aspect and the design influences whether actors in the product development function find the aspect relevant to consider or not. Additionally, this causal link may explain why many social aspects of the companies' products, such as no forced labor, are considered by purchasers rather than designers.

4.4 ACTORS INVOLVED

This subchapter describes findings that relate to actors (individuals and/or groups) that are involved when sustainability aspects are included in product development.

4.4.1 SEVERAL ACTORS ARE INVOLVED

The case study shows that several internal actors can be involved, at least to some extent, when including sustainability aspects in product development. Inclusion of sustainability aspects in product development is therefore an issue for more actors than just designers. For example, designers, project managers, product owners, purchasers, system/product safety engineers, top management (here defined as persons or groups of people who direct and control an organization at a high level in a company, including the highest level, adapted from ISO 14001:2015), environmental managers and coordinators. External actors can also be involved when including sustainability aspects in product development at large manufacturing companies. For example, the customer, legislative authorities, and additional companies working in a joint action group.

Some actors have a dedicated responsibility to include, manage or fulfil sustainability aspects and/or requirements, e.g., the environmental coordinators and the project environmental coordinator at Company A, and employees in the Environment, Safety and Health & Sustainability function at Company B. These actors can be viewed as formalized versions of the informal *environmental champion*, identified in companies studied by McAloone (2000).

Project managers are involved at both Companies A and B when including sustainability aspects in product development. This study therefore corroborates the study by Brones et al. (2014), who found that project managers are important actors for the inclusion of environmental aspects in product development. According to Ölundh and Ritzen (2004) project managers at Scania have a “*central role*” in regard to inclusion of environmental aspects in the product requirements. The similarity between Scania, as described by Ölundh and Ritzén (2004), and Companies A and B is that project managers are involved. Indeed, several actors are involved when sustainability aspects are included in product development.

4.4.2 THE PRODUCT OWNER ROLE

To develop products with low environmental impact it is important that product requirements for low environmental impact are included in the product specification (Luttrupp and Lagerstedt, 2006); a statement that is considered applicable for any sustainability aspect. The case study strongly indicates that the *product owner* is one of the key actors for the inclusion of sustainability aspects in

product development, and in the product requirements in particular. The *product owner* processes customer needs (Companies A and B), legislative requirements (Company A), environmental policies and internal requirements (Company A) and business opportunities (Company B) into the early product specification (includes the early, initial set of product requirements). Since the *product owner* generates the early product specification, the *product owner* affects *which* aspects are processed into product requirements and included in the product specification. In addition, the *product owner* affects how *free from solutions* (i.e., tell *what* to do and not *how*) the formulations of the product requirements in the product specification are.

According to Ulrich and Eppinger (2008) it is important that the product requirements are free from solutions. The product requirements must be free from solutions in order to increase the design space and thereby increase the chances that innovative solutions are developed. The *product owner* thereby affects the possibility for the product development project to come up with innovative solutions that contribute low environmental and social impact. For example, developing products that cause radically less environmental impact than a former product, and which generate a high return on investment at the same time. However, Deutz et al. (2013) argue that the actors providing the design engineers with product requirements are not always familiar with the importance of making the product requirements free from solutions.

The findings from the case study indicate that the *product owners* at Companies A and B influence the inclusion of sustainability aspects in early product requirements more than the designers. Similarly, McAloone (2000) found that the designers at the companies studied could not influence environmental decisions taken at pre-product specification stages. Additionally, Lee-Mortimer and Short (2009) generate a hypothesis that the scarce inclusion of environmental and social aspects in companies' "mainstream" product development is caused by a lack of efficient product development practice, causing a lack of environmental and social aspects in the product specification. The authors further argue that instead of a focus on the application of methods, focus should be on the companies' current practice of generating the product specification. For example, "... *education and providing designers with the tools to consider DfS [Design for Sustainability] from early development stages will be pointless as it [sic] very often the marketing and management who seem to decide on key product requirements, including its sustainability*" (Lee-Mortimer and Short, 2009). The importance of the practical work conducted for generating the product specification is reflected also in a suggestion by Hallstedt et al. (2013) for the companies they studied; define a

generic methodology to identify sustainability aspects so that “*no important sustainability aspect is neglected*”.

Some companies may have no actor called *product owner*. For example, at a company studied by Deutz et al. (2013) the early product requirements were provided by the marketing department. One should therefore carefully understand and focus on what is done and by whom, rather than on what the actors are called.

Despite the strongly indicated importance of *product owners* for the inclusion of sustainability aspects in product development, there is a lack of studies on the role of *product owners* in regard to inclusion of sustainability aspects in product development, and in product requirements in particular. More specifically, there is a lack of studies on how sustainability aspects are elicited and prioritized, and “*how these sustainability aspects are formulated in [the] early product requirements*” (Paper I), by *product owners*. In line with this, Brønes and de Carvalho (2015) identified a lack of studies on the role of portfolio management for the inclusion of environmental aspects in product development. Similarly, Dangelico and Pujari (2010) suggest increasing the understanding of how companies work with “*green product portfolio management*”.

To summarize, the *product owner* is a key actor for the inclusion of sustainability aspects in product development, and in particular for the inclusion of sustainability aspects in product requirements.

4.5 GOALS APPLIED

The case study indicates that goals for the inclusion of sustainability aspects in product development mainly apply at a strategic level, rather than to all product development projects. Companies A and B have goals for the inclusion of sustainability aspects in product development. These goals apply mainly to their portfolio of products rather than to individual product development projects. The portfolio level is in this thesis interpreted as *strategic*. For instance, one goal at Company A is “*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*” (Paper I). This goal applies to actors and can indirectly influence which chemical products and materials that are selected when developing Company A’s products. Since this goal, as formulated, is not meant to apply directly to a product development project, it is considered to be *strategic*. One example of a goal at Company B is, “*in the company’s largest business areas, the degree of energy efficiency of sold products on average shall be increased by 1%*” (Paper I). The

increase of 1% is measured after a certain period of time (a couple of years). This goal applies to the entire portfolio of Company B's main products and is, therefore, a strategic goal.

Information on whether and how other manufacturing companies than Companies A and B apply goals for the inclusion of sustainability aspects in their product development has not been found in the literature covered in this thesis. However, according to Ölundh and Ritzén (2004), the large Swedish vehicle manufacturer Scania, used (in year 2004) environmental performance as one of a total of eight technical parameters for evaluating project ideas. The environmental performance parameter was used in the "*pre-specification*" phase of Scania's product development projects. The *pre-specification* phase is by the author of this thesis interpreted as the planning phase, described in Figure 7. This strategic way of working at Scania is considered having similarities with Companies A and B in that Companies A and B apply goals for the inclusion of sustainability aspects in their product development mainly on a portfolio of products. According to Ölundh and Ritzén (2004), Scania strives however for including "...*clear environmental demands and targets*" in all product specifications. A similar "strive" seem to exist within the product development function at Company B, see challenge number 6, CB6, in Paper III. In addition, Tingström et al. (2006) describe that ABB (in 2006) used an "... *approach that integrates sustainability goals into product development projects*". However, how this approach works in more detail, for example, whether the "approach" at ABB ensures sustainability goals are applied to *all* its product development projects, is not described but would be interesting to know.

It is important to note that not all product development projects are necessarily affected by strategic goals. For example, even though Company B applies environmental goals at a product portfolio level, Company B describes a situation where it is pressed by competitors and in that situation it is considered economically wiser, according to management at Company B, to *not* include a requirement for increased energy efficiency in the product development project (see again, challenge number 6 for Company B, CB6, in Paper III). Elaborating further on this situation; it is interesting that the decision (taken by management at Company B) to not include a requirement for increasing energy efficiency is taken before the concept development phase starts. There will be little chance to include requirements for energy efficiency when the product development project enters the concept development phase, because the decision is already taken to prioritize other requirements than the increase of energy efficiency. Boks (2006), who studied manufacturers within the electronics industry in Asia, found that such "*lack*

of environmental goals and vision for individual development projects” is a large barrier for having ecodesign products brought to the market.

To summarize, the findings in this thesis indicates that, at the case companies, goals for the inclusion of sustainability aspects in product development are applied mainly at a strategic level, rather than to all individual product development projects. Additionally, the case study shows that all product development projects are not necessarily affected by strategic goals.

4.6 METHODS USED

The case study indicates that there are manufacturing companies that apply *conventional* methods (methods that can be applied in product development without the inclusion of environmental or social aspects) when including sustainability aspects in product development. Examples of conventional methods applied at Companies A and B are surveys (Ulrich and Eppinger, 2008; Ullman, 2010) and interviews (Ulrich and Eppinger, 2008) to acquire feedback and thoughts from stakeholders (Paper I). Additional examples of conventional methods are Computer Aided Design (CAD) (Ulrich and Eppinger, 2008; Ullman, 2010) and Product Data Management (PDM) systems (Ullman, 2010), applied by Company A, and mathematical energy efficiency calculations, applied by Company B. A mathematical energy efficiency calculation is in this thesis interpreted as a technical model, as described by Ulrich and Eppinger (2008) and Ullman (2010). Similarly, four vehicle manufacturers in Sweden apply conventional methods, such as “*simulation on energy use, [and] combustion processes*” (Poulidikidou et al. (2014) as “*important and desired means for reducing the environmental impact from their products*”. This method is summarized as *Simulations/laboratory testing* in Table 6.

It is striking that many of the ecodesign methods described in literature are not identified at Companies A and B; for instance, “*Ten golden rules*” (Luttropp and Lagerstedt, 2006), EEA (Lindahl et al., 2000), QFDE (Masui et al., 2003);) and the MET-matrix (Brezet and van Hemel, 1997, as referred to by Bovea and Pérez-Belis, 2012).

None of the conventional methods described above are included in lists of ecodesign methods compiled by Lindahl and Ekermann (2013), Rousseaux et al. (2017), Bovea and Pérez-Belis, (2012), and Rossi et al. (2016). Why not? Are the definitions of an ecodesign method too narrow and exclude conventional methods, even though they can be used when sustainability aspects are included in product development? Or, has the role of conventional methods when including

sustainability aspects in product development been largely ignored in prior research? Perhaps the answer to both these questions is “yes”. However, the author believes the main reason to be that the role of conventional methods has been ignored.

Baumann et al. (2002) argued that traditional ecodesign methods are not sufficient, and perhaps not even necessary, to reduce the environmental impact from products. The findings in the case study corroborates the first part of the statement by Baumann et al. (2002) that ecodesign methods are not sufficient. The reason is that Companies A and B apply other methods which seem to be useful for them, e.g., conventional methods. However, the findings in the case study do not corroborate the part of the statement that ecodesign methods might not even be necessary, since, for example, lists with banned and restricted chemical products and materials (described as an ecodesign method by Rousseaux et al. 2017) are used by both companies and appear to be useful.

The case companies have customized their methods to make them useful. This is similar to how the vehicle companies and ABB, studied by Poulikidou et al. (2014) and Tingström et al. (2006), respectively, have customized methods to make them useful.

In addition, the respondents were explicitly asked about possible methods they thought were lacking. Company B was interested in testing methods that can support the inclusion of sustainability aspects in product development earlier than at the end of the concept development phase. Company A emphasized the importance of integrating environmental requirements in conventional methods. In line with Baumann et al. (2002), both respondents at Company A argued primarily for better use of the methods they already had, rather than arguing there is a lack of methods to use. Suitable methods for the companies to test and evaluate may already exist but were unknown to the respondents.

Noteworthy is that LCA is used at both companies, but for different reasons. At Company A, when required by customers and to verify requirements that require results from LCA, but not for applying a life cycle perspective in product development. This is similar to how some of the companies studied by Hallstedt et al. (2013) use LCA; those companies applied LCA to comply with legislation and to fulfil customer demands. At Company B, the LCAs are conducted for marketing reasons (in Environmental Product Declarations) and to learn about the products’ environmental impact throughout the products’ life cycle. The knowledge developed from the LCAs is used for understanding the environmental hotspots of

the products' life cycle. Most LCAs at Company B were conducted more than ten years ago. However, the knowledge is still valid and useful enough, according to Company B, because the company's (main) product has not changed significantly since the LCAs were conducted. They actually conducted several LCAs which all gave similar results. Additional LCAs would therefore, according to the respondents at Company B, mainly constitute a cost rather than contribute with important new knowledge. Additional LCAs on the same type of product are therefore not conducted, even though new product development projects have started. There are however additional products in Company B's product portfolio for which no LCA has yet been done (see e.g., challenge number 1 for Company B, CB1). These additional products differ greatly from Company B's main product. Therefore, to understand the environmental impact from these additional products, LCAs will have to be conducted.

Whether the LCAs at Company A and B are conducted within specific product development projects or for some other type of project, such as a project performed only for conducting the LCAs, is not clear from the case study. However, the case study strongly indicates that an LCA does not need to be conducted within each specific product development project to be useful for product development projects. This finding is in line with the following view at one of the manufacturing companies studied by Jönbrink and Melin (2008); LCA is *"very useful for marketing and also to gain knowledge for coming [product] development projects"*.

To summarize, the case study indicates that the role of *conventional* methods when including sustainability aspects in product development is largely ignored. The case companies have customized their methods to make them useful. There are examples of other manufacturing companies that customize their methods too. There is an interest at Company B to test methods that provide support for inclusion of sustainability aspects in the stages before the end of the concept development phase. Company A emphasized integration of environmental requirements in conventional methods, as well as, most importantly, better use of the methods it already has. The case study strongly indicates that an LCA does not need to be conducted within each specific product development project to be useful for product development projects.

5 CHALLENGES

*This chapter is dedicated to answering RQ2 (**Which challenges do manufacturing companies face when including sustainability aspects in their product development?**) and does so by analysing and discussing the challenges related to the inclusion of sustainability aspects in product development in general, and in Companies A and B in particular. The main focus of the analysis is to identify challenges that are not clearly described in the framework of Dekoninck et al. (2013), and to propose suggestions for an update of that framework.*

This chapter will describe findings from a literature study of challenges within ecodesign and from an empirical study that identified challenges that manufacturing companies can face when including sustainability aspects in their product development.

5.1 CHALLENGES WITHIN ECODESIGN

The literature study identified challenges within ecodesign. The challenges are divided into four categories: (1) systems and success level (what to sustain and the path towards sustainability), (2) strategy level (guides what to invest in), (3) action level (the activities done), or (4) methods (methods applied), and are described in Table 8. See subchapter 2.2 Literature study for a more detailed explanation of the four categories into which the challenges are divided.

Table 8 shows that most challenges within ecodesign relate to unclear ideas of what to sustain, and an unclear idea of the path towards sustainability. These unclear ideas imply that a systems perspective should be more present than it is today in research and other activities. For example, by reflecting about whether a certain activity, before it is conducted, actually contributes to sustaining society and the surrounding ecosystems, and what rebound effects may occur. Additionally, challenge number “4. *Confusion about what a sustainable business is, and the scope of ecodesign compared to other similar approaches*” (Table 8), sheds light on the problem discussed by Isil and Hernke (2017) and Elkington (2018), that *balancing* environmental, social and economic aspects may *not* lead to sustainability. Clearly, *sustainable* (or *sustainability*), is a word that can be, and is, interpreted differently, generates confusion and therefore must be treated with care.

Challenge number “3. *To complement ecodesign with social and economic issues*” (Table 8) influenced the succeeding research (Papers I and III) in that social and economic aspects were considered in addition to environmental aspects.

An unexpected finding is that challenges identified in the literature study are not solely faced by employees in companies. For example, challenge number “1. *Lack of tools that are built to achieve goals at a system and success level*” is, rather, faced by researchers striving to reduce the environmental impact from products developed by manufacturing companies. This finding influenced the succeeding research, Papers I and III, in that only manufacturing companies were studied.

Table 8 Sixteen challenges within ecodesign were found in the literature These sixteen challenges are adapted from Paulson and Sundin (2015) (Paper II). The categories of the columns are (1) Systems and success level (what to sustain and the path towards sustainability), (2) Strategy level (guides what to invest in), (3) Action level (the activities done), and (4) Method level. See subchapter 2.2 Literature study for a more detailed explanation of the categories of the columns.

System and success level	Strategy level	Action level	Method level
1. Lack of tools that are built to achieve goals at a system and success level	7. Overcome barriers when implementing ecodesign	11. Ecodesign practice is still limited	14. Tools do not fit the purpose well enough
2. To better understand and/or influence end-user's behaviours when performing ecodesign	8. Knowing how to implement ecodesign in a company	12. Lack of environmental (or sustainability) oriented requirements in product specifications	15. Clearly understand why a tool might be needed
3. To complement ecodesign with social and economic issues	9. Lack of expert knowledge in how to implement ecodesign	13. Including the whole life cycle and value chain of a product	16. Lack of environmental impact information
4. Confusion about what a sustainable business is, and the scope of ecodesign compared to other similar approaches	10. Lack of time and other resources for implementing ecodesign		
5. How to create effective legislation that makes an improvement to a system and success level			
6. Possible future hazardous materials/substances are not banned often enough			

Next, challenges faced by manufacturing companies are analyzed and discussed.

5.2 CHALLENGES FACED BY MANUFACTURING COMPANIES

The case study has contributed 21 novel, detailed descriptions of challenges faced by Companies A and B when including sustainability aspects in product development. The 21 novel detailed descriptions of challenges, including what causes them and who face them, are fully described in Paper III. A summary of the 21 challenges is presented in Tables 9 and 10. The challenges described in Tables 9 and 10 are the respondents' direct answer to the following interview question: *"Which challenges does your companies face today when including sustainability aspects in product development?"* (Paper III). By direct is meant the answer given by the respondent before any follow-up question was asked.

The 21 identified challenges in Tables 9 and 10 are examples of challenges that manufacturing companies can face when including sustainability aspects in product development. Two of the challenges identified are proposed to be added to the comprehensive framework of challenges created by Dekoninck et al. (2016) shown in Appendix A.

The challenges identified at Companies A and B were compared with each other and with challenges and barriers identified in five prior studies (Jönbrink et al., 2013; Schulte and Hallstedt, 2017a; van Hemel and Cramer, 2002; Hallstedt and Thompson, 2011; and Dekoninck et al., 2016). The five studies compared with were selected because they describe challenges and barriers related to the inclusion of sustainability aspects in product development and include first hand empirical data. In addition to first hand empirical data, the study by Dekoninck et al. (2016) includes a comprehensive framework of challenges (which also includes barriers, obstacles and hurdles), presented in Appendix A. The comparison of challenges was made according to the methodology described in subchapter 2.3.5 Comparison of challenges and reasons for challenges, in which challenges were classified as *same*, *similar*, *have similarities* or *"-"*. The result from the comparison is described in the text below and in Table 11 (p. 70). The symbols used in Table 11 parallels *same*, *similar* and *have similarities*, in that *same* = ●, *similar* = ▲, and *have similarities* = ■.

Table 9 The fourteen challenges ($N_A=14$) identified at Company A. CA1 stands for Challenge, company A, challenge number 1. The challenges are adapted from Paulson and Sundin (2019) (Paper III). Detailed descriptions of all these challenges can be read in Paper III.

Challenge ID	Challenges the companies face when including sustainability aspects in product development
CA1	Getting sustainability-related information from suppliers about chemicals and substances they use in their products
CA2	Buying components that include chemicals or substances, for which permission to use must be applied for, from companies in countries that do not have to follow the same legislation as Company A
CA3	Finding out how to efficiently solve the problem that occurs when two pieces of legislation (e.g. environmental legislation), which have to be complied with, contradict each other
CA4	Making the suppliers of Company A fulfil the sustainability requirements that Company A places on them
CA5	Finding new suppliers or redesigning components in order to maintain satisfactory delivery reliability in situations when components or substances the company uses vanish from the market
CA6	Following up and ensuring that their list of restricted substances is complied with
CA7	Having a good understanding within Company A of all relevant legislation/directives in all countries Company A sells products to
CA8	Understanding how the environmentally related goals (e.g. climate goals) that the UN, the EU, various nations etc. have agreed upon can be concretized into relevant key performance indicators (KPIs) and goals applicable at Company A
CA9	Investigating whether Company A has conflict minerals in its products
CA10	Managing and working with Company A's comprehensive list of regulated chemicals and substances
CA11	Making the actual substitution of HCS within Company A's own factories and at its suppliers, while still fulfilling all technical requirements for the product
CA12	Helping in-house engineers understand the environmental requirements well, in order to give them the ability to see which of the environmental requirements allow for room to manoeuvre and which do not
CA13	Including environmental aspects when evaluating suppliers for purchasing components
CA14	Making suppliers aware that they have to take responsibility for raising their own knowledge of environmental requirements, and to make them raise that knowledge

Table 10 The seven challenges ($N_B=7$) identified at Company B. CB1 stands for Challenge, company B, challenge number 1. The challenges are adapted from Paulson and Sundin (2019) (Paper III). Detailed descriptions of all these challenges can be read in Paper III.

Challenge ID	Challenges the companies face when including sustainability aspects in product development
CB1	To efficiently and as soon as possible have found relevant, measurable KPIs that can be followed up for the products in their portfolio that are not yet affected by the latest version of Company B's formal product development process
CB2	Allocating time and money to develop their product development engineers and managers in a way that they have a sustainability mindset when they solve problems and invent new products, in general
CB3	Making sure the social requirements that are placed on the suppliers are complied with, and that those requirements are followed up
CB4	Including sustainability aspects already in the planning phase of the product development projects in a better way than is currently done
CB5	Explaining and internally marketing Company B's sales activities in business segments which some of Company B's employees do not consider contribute to sustainable development
CB6	Keeping up the work of improving their products from a sustainability viewpoint in some situations where Company B is pressed by competitors
CB7	Educating and convincing some of their customers to invest in smarter, smaller and more energy-efficient products that can save them money, reduce maintenance and are as dependable as former products

More than half of the challenges at Companies A and/or B have at least similarities with the subheadings of the framework of Dekoninck et al. (2013), which is concluded from the ●, ▲, ■ symbols in 12 of the 21 rows in the third column of Table 11.

Because CA4 and CB3 are classified as the *same*, see the fifth row in Table 11, there are actually only 20 “different” and “unique” challenges within the 21 challenges described by Companies A and B, listed in Tables 9 and 10.

The challenge CA4, “*making the suppliers of Company A fulfil the sustainability requirements that Company A places on them*” (Table 9) and the challenge CB3, “*making sure the social requirements that are placed on the suppliers are complied with, and that those requirements are followed up*” (Table 10) are classified as *same*, i.e., the ● symbol, see the upper marked row in Table 11.

Table 11 Comparison of challenges between Companies A, B and selected prior studies. The symbols used when comparing two challenges are here presented in declining order of similarity: same = ●, similar = ▲, have similarities = ■. Numbers in brackets refer to specific subheadings of challenge in the framework of Dekoninck et al. (2016) (see Appendix A). The Table is based on Paulson and Sundin (2019) (Paper III). The similarities within the rows marked blue are commented on in this subchapter.

Company A	Company B	Dekoninck et al. (2016)	Hallstedt and Thompson (2011)	Schulte and Hallstedt (2017)	van Hemel and Cramer (2002)	Jönbrink et al. (2013)
CA1	-	● (3.2.4)	-	■	-	-
CA2	-		-	-	-	-
CA3	-		-	-	-	-
CA4	● (CB3)	■ (3.2.2)	-	▲	-	-
CA5	-		-	-	-	-
CA6	■ (CB3)	■ (4.2.2)	-	■	-	-
CA7	-	■ (4.2.2)	-	-	-	-
CA8	▲ (CB1)	■ (4.2.2)	-	▲	-	-
CA9	-	▲ (5.2.1)	-	■	-	-
CA10	-	▲ (4.2.2)	-	■	-	-
CA11	-	▲ (4.2.1/5.2.2)	■	-	●	-
CA12	-		-	-	-	-
CA13	-	-	-	-	-	-
CA14	■ (CB3)	▲ (3.2.3)	-	-	-	-
▲ (CA8)	CB1		-	■	-	-
-	CB2	● (4.3.1/4.3.2)	-	-	■	▲
● (CA4)	CB3		-	▲	-	-
-	CB4	● (4.1.5)/ ■ (4.2.2)	-	-	-	-
-	CB5		-	■	-	
-	CB6	● (4.2.1)	●	-		
-	CB7	-	-	-	-	●

Additionally, CA4 and CB3 are classified as *similar* to, i.e., the ▲ symbol, and thereby in line with “... [having] control over sustainability aspects throughout the whole supply chain...”, identified by Schulte and Hallstedt (2017a).

However, CA4 and CB3 are only considered to have similarities, i.e., the ■ symbol, with “*changing the type of interaction in the value chain from transactions to collaborations*”, which is one of the subheadings of challenges in the framework of Dekoninck et al., 2016). Clearly, the framework of Dekoninck et al. (2016) lacks a subheading of challenges that can be classified as *same* or *similar* to CA4 and CB3, especially because Schulte and Hallstedt (2017a) also identified a challenge

similar to CA4 and CB3. Therefore, the author of this thesis formulated a merged version of the challenges at Companies A and B that reads:

“making suppliers fulfil the sustainability requirements that are placed on them”

(adapted from Paper III).

The formulation above keeps the principal meaning of CA4 and CB3, and is proposed for inclusion in a proposed updated version of the framework of Dekoninck et al. (2016), shown in Appendix B.

Additionally, the challenge CA8, *“Understanding how the environmentally related goals (e.g. climate goals) that the UN, the EU, various nations etc. have agreed upon can be concretized into relevant key performance indicators¹⁵ (KPIs) and goals applicable at Company A”* (Table 9) and the challenge CB1, *“To efficiently and as soon as possible have found relevant, measurable KPIs that can be followed up for the products in their portfolio that are not yet affected by the latest version of Company B’s formal product development process”* (Table 10) are classified as *similar* (▲), see the lower marked row in Table 11. Moreover, CA8 and CB1 are classified as *similar* (▲) to *“translating these future requirements into correspondingly high prioritization and actions in the present”*, identified by Schulte and Hallstedt, (2017a). However, CA8 and CB1 only have similarities (■) with *“difficult to manage customers’ requirements for ecodesign”* in Dekoninck et al. (2016).

By the same reasoning as earlier, the framework of Dekoninck et al. (2016) clearly lacks also a subheading of challenges that can be classified as *same* or *similar* to CA8 and CB1. Therefore, a merged version of the challenges at Companies A and B is formulated and reads:

“Transforming sustainability aspects, or general goals, into measurable requirements that contribute to reduced environmental impact from products while at the same time contributing to competitive profit”

(adapted from Paper III).

¹⁵ A key performance indicator (KPI) is a metric that *“shows how well an economy, company, ... [or] project, etc. is doing”* (adapted from dictionary.cambridge.org)

The remaining challenges were compared in the same way as described above. However, no further proposals for updates to the framework of Dekoninck et al. (2016), based on the comparison between challenges, have been made. Note that there are eight challenges faced by the case companies (CA2, 3, 5, 12,13 and CB1, 5 7) which are not identified by Dekoninck et al. (2016). There are therefore many more novel challenges identified than the two challenges proposed for inclusion in the framework of Dekoninck et al. (2016), described in this subchapter. However, as described in subchapter 2.3.5 Comparison of challenges and reasons for challenges, only challenges identified as at least similar in both Companies A and B and in one additional prior study are proposed for inclusion in the framework of Dekoninck et al. (2016).

The framework of Dekoninck et al. (2016) covers mainly environmental aspects, since the authors focus on *ecodesign*. One may therefore wonder why this thesis has widened the scope to sustainability aspects and not kept the focus on environmental aspects. The argument is that *ecodesign* itself is widening its scope and has started to include aspects other than environmental aspects, see e.g., Boks and McAlloone (2009) and challenge number 3 in Table 8, in this thesis.

The analysis described in this subchapter has tested the completeness of the framework of Dekoninck et al. (2016) (Appendix A) and provides a proposed update of the framework with two additional challenges (Appendix B).

An overall description of which challenges manufacturing companies can face when including sustainability aspects in product development is considered to be covered well by the proposed updated framework of Dekoninck et al. (2016) in Appendix B and Stewart et al. (2016). One must note that, in addition to challenges, the framework of Dekoninck et al. (2016) includes what other people may call barriers and hurdles. Therefore, the comprehensive list of “*barriers to implementing different types of sustainability approaches*” by Stewart et al. (2016) is also found relevant for understanding which challenges manufacturing companies can face when including sustainability aspects in product development. In addition to the analysis and discussion in this subchapter, Paper III is considered to contribute a deeper understanding of the nature of the challenges.

The next chapter will describe the analysis of reasons for challenges, which among other things results in a proposal to add one additional challenge to the framework of Dekoninck et al. (2016).

6 REASONS FOR CHALLENGES

This chapter is dedicated to answering RQ3 (Why do manufacturing companies face challenges when including sustainability aspects in product development?) and does so by analysing and discussing internal and external reasons for the challenges Companies A and B face when including sustainability aspects in product development.

All reasons for the challenges identified at Companies A and B (Table 9 and 10) originate in the case study and are described in detail in Paper III. The reasons for the challenges are based on the respondents' perspectives of challenges that their company faces when including sustainability aspects in product development, and the respondents' perspectives of what is causing these challenges.

Reasons for challenges which the author considered to mean the same thing were grouped into one rephrased version. These "rephrased versions" are analyzed and discussed in this chapter. Analysis of the reasons for challenges was performed by comparing these "rephrased versions" (hereafter only called "reasons") with findings from prior research.

The comparison resulted in classifying reasons for challenges (at Companies A and B) and findings from prior research as *similar*, *have similarities* or *"-"* (*no similarity*). See subchapter 2.3.5 Comparison of challenges and reasons for challenges, for a more detailed description of how the comparison was performed.

"Something" causes a challenge. This "something" is here described as a "reason". There can be several reasons for a challenge. Additionally, there can be a chain of reasons for a challenge, as exemplified in the left side of Figure 8 (next page). For example, in CA1 in Paper III, a *"lack of legislative requirements..."*, is a reason for the unwillingness of the supplier to share information about the chemical content of its products, which in turn is a reason for challenge CA1; *"getting sustainability related information from suppliers about chemicals and substances they use in their products"*. An additional reason for CA1, exemplified in the right side of Figure 8, can be that the supplier *"does not have the information readily available"* (Paper III).

Figure 8 A challenge to include sustainability aspects in product development can be caused by several “reasons” for the challenge. There can be a chain of reasons for a challenge.

For a manufacturing company, the reasons can be internal or external. Internal means that the reason originates within the company and is considered by the author of this thesis as being able to be controlled by the company. External reasons originate externally (to the company) and cannot be controlled by the company. In addition, a barrier or an obstacle could be seen as a reason for a challenge. A total of five main internal and nine main external reasons were identified at Companies A and B.

6.1 INTERNAL REASONS FOR CHALLENGES

The five main internal reasons for challenges mentioned by the respondents at Companies A and B are described below. The internal reasons for the challenges are presented in order of how commonly (roughly) they were mentioned by the respondents at Companies A and B. Similarities between these nine external reasons for challenges and findings from prior studies by other researchers are commented on.

Many challenges, barriers, and some reasons for challenges described in prior studies by other researchers, are similar to, or have similarities with, the internal reasons for the challenges identified at Companies A and B. These similarities are included and shown in the list below.

The internal reasons for the challenges identified are:

1. *Lack of relevant knowledge (and/or awareness) in the company,*

is a reason mentioned for CA2, 3, 7, 8, 10, 11 and 12 at Company A, i.e. in 7 of 14 ($N_A=14$) challenges, or 50% of the challenges at Company A (see Figure 9). It is also a reason mentioned for CB2, 3 and 4 at Company B, i.e. in 3 of 7 ($N_B=7$) challenges at Company B, or 43% (see Figure 9). The specific

knowledge and/or awareness that is lacking varies. For example, in CA2 the knowledge is about managing requirements, related to restricted chemicals and substances, in the supply chain, and in CB4 it is the awareness that it is important to proactively search for sustainability aspects, if such aspects are to be identified at customers.

In addition, this internal reason is considered as being similar to, or having similarities with:

- *“Requires a large amount of knowledge development both within the design department and the supporting business functions”* and *“Staff do not have the level of environmental knowledge required for effective ecodesign”*, identified by Dekoninck et al. (2016).
- *“Lack of knowledge”*, identified by Schulte and Hallstedt (2017a).
- *“Lack of competence”* (translation by the author of this thesis), identified by Jönbrink et al. (2013). *Competence* is in this challenge interpreted as *knowledge*.
- *“Lack of skills/knowledge/training”*, a *“barrier”* identified by Stewart et al. (2016).

2. *Addressing the challenge is too complex and resource demanding (money, time and manpower) for the company,*

is a reason mentioned for CA2, 3, 5, 6, 7, 8, 9 and 10 at Company A, and for CB1 and CB6 at Company B. At Company A, the reason is mainly about the complexity of the challenge and that addressing the challenge requires much time. At Company B, it is mainly about requirements for time and money.

In addition, this internal reason is considered as being similar to, or having similarities with:

- *“No extra resources allocated to new ecodesign initiatives”* and *“No extra time allocated to new ecodesign initiatives”*, identified by Dekoninck et al (2016).
- *“The company lack [sic] sufficient time to realise the option in question”*, which was used as a predefined answer in interviews conducted by van Hemel and Cramer (2002). van Hemel and Cramer (2002) investigated which, of twelve different barriers, hamper the realization of the ecodesign improvements, such as using less packaging, at SMEs.

- “*Lack of time and resources*” (translation by the author of this thesis), a “*barrier*” identified by Jönbrink et al. (2013).
- “*Time constraints*”, which Poulidikou et al (2014) describe as a reason for challenges that relate to integration of environmental aspects in product development.

3. *Initiatives other than the more sustainable initiative, contribute more efficiently to the economic goals,*

is a reason for CB5 and CB6 at Company B. More specifically, the actors in Company B who decide what initiatives to invest in (e.g., what knowledge development projects, technical development projects and product development projects to run) think there are initiatives other than the more sustainable one (e.g., more “energy efficient” or “sustainable development-aligned” initiatives) that contribute even better to Company B’s economic goals.

One may see this as a competition where a more sustainable initiative *competes* with other less sustainable initiatives for the money and other resources available for investment. Therefore, to be selected, the more sustainable initiative has to be among the initiatives that are considered to give the most return on investment and/or contribute best to requirements and goals for profit.

Two different initiatives may contribute to the same return on investment and/or profit, however, within different time frames. Regarding the time frame for return on investment and/or profit; the author believes from an overall level it is the shareholders’ and company owners’ perspective on *when* the return from investments and/or profit are to be realized that matters most. As long as the business can be operated as planned. Nothing else identified in the empirical data limits the time perspective for profit and return on investment.

In addition, this internal reason is considered as being similar to, or having similarities with:

- “*Lack of profitability*” (translation by the author of this thesis), a “*barrier*” identified by Jönbrink et al. (2013).
- “*Cost is still the main driver in NPD [New Product Development] activities and it is very difficult to implement an ecodesign solution that is not cost-effective*”, identified by Dekoninck et al. (2016), This “*challenge*” is included in the subheading in their framework called “*Difficult to take decision when there are trade-offs between environmental issues and the other aspects (such as cost, quality, security*

...)” (see Appendix A). However, this subheading emphasizes the difficulty of making decisions rather than the difficulty of prioritizing environmental aspects over cost, quality, security, etc. The author of this thesis believes Dekoninck et al. (2016) actually mean the latter. Therefore, a clearer formulation is needed.

- “*Difficulty to elaborate business case, conflict, difficulty to manage trade-offs*”, a “*barrier*” identified by Stewart et al. (2016).
- “... (i) *the relation between sustainability and profitability is not obvious; (ii) product cost might get higher and it is unclear if all customers are willing to pay extra for a more sustainable product, and in the short term there might be; (iii) higher investment costs; and (iv) a perceived risk of decreased profitability*”(Schulte and Hallstedt, 2017a), which are all reasons for challenges related to the inclusion of sustainability aspects in product development. These reasons for challenges are also related to the strong and important barrier “...*costs and short-term economic thinking...*”, also described by Schulte and Hallstedt (2017a).
- The difficulty to recognize, understand and manage trade-offs “*in a way that maximizes the success of the product*”, and to get a “*reasonable return on investment*” from developing the product, makes product development, in general, challenging (Ulrich and Eppinger, 2008). These are by the author of this thesis interpreted as reasons that make product development, in general, challenging.

4. *Personal values/beliefs about what is sustainable is not in line with the company's activities,*

is a reason mentioned for CB5, at Company B. More specifically, some employees question selling products to customers in certain business segments that the employees consider do not contribute to sustainable development. No similar reason for challenges described in prior studies has been identified.

5. *Functional requirements are most important and must be fulfilled,*

is a reason mentioned for CA13, at Company A. In the context of Company A, functional requirements means the technical functionality, or purpose, of the product or subsolution.

This internal reason is considered as being similar to:

- “*The option creates a conflict in connection with actual functional product requirements*”, a “*barrier*” described by van Hemel and Cramer (2002).

A summary of the five main internal reasons for challenges, and how commonly they cause the challenges identified at Companies A and B, is presented in Figure 9. Each internal reason is shown on the X-axis. The share of challenges at each company that are caused by each internal reason is described on the Y-axis. For example, number 2: *addressing the challenge is too complex and resource demanding (money, time and manpower) for the company*, is mentioned in 8 of 14 ($N_A=14$) challenges at Company A, i.e., in 57% of the challenges at Company A. The same reason, number 2, is mentioned in 2 of 7 ($N_B=7$) challenges at Company B, i.e., in 29% of the challenges at Company B.

Figure 9 The five main internal reasons for challenges, and how commonly they cause the challenges identified at Companies A and B. The Y-axis shows the share (measured in %) of challenges at each company that are caused by each internal reason. The internal reasons are described on the X-axis.

The similarities identified show that reasons numbers 1, 2, 3, and 5 (identified at Companies A and B) are in line with findings from prior studies by other researchers.

Reason number 3: *initiatives other than the more sustainable initiatives, contribute more efficiently to the economic goals*, is not described in the framework of Dekoninck et al. (2016) and is therefore proposed to be added to their framework. It is considered appropriate to rephrase it as a challenge rather than a barrier because the framework is said to list *challenges*. The rephrased proposal, which is considered to retain the original meaning, reads:

Identifying how to reach economic goals more efficiently with a more sustainable initiative or solution than other initiatives.

The formulation of the challenge is slightly different from the corresponding proposed challenge described in the conclusion section of Paper II, but is considered to be clearer. The motives for updating the framework of Dekoninck et al. (2016) with this challenge are: (1) the similarities identified between challenges, barriers and reasons for challenges in prior research; and (2) a clear corresponding subheading of challenges in their framework is lacking. The challenge is put into subheading number 1.1.3 in the proposed update of the framework, shown in Appendix B.

A practical implication of this challenges is: The chance increases that a more sustainable product becomes developed by a manufacturing company if one can demonstrate how the development of that more sustainable product improves the company's ability to reach its economic goals more efficiently than *other* initiatives at the company do.

Since manufacturing companies focus on risk and opportunities it sounds reasonable to help them identify important economic risks and economic opportunities related to sustainability aspects, and try to monetarize or in other ways describe the value of acting on the risks and opportunities.

Perhaps will "more sustainable initiatives or solutions" contribute more efficiently to the economic goals of manufacturing companies if these initiatives or solutions are derived from sustainability aspects that are related to clear economic risks and opportunities. Why? Because the findings in this thesis strongly indicate that manufacturing companies focus on those sustainability aspects that are related to clear economic risks and opportunities.

6.2 EXTERNAL REASONS FOR CHALLENGES

The nine main external reasons for challenges mentioned by the respondents at Companies A and B are described below. The reasons for the challenges are

presented in order of how commonly they were mentioned by the respondents at Companies A and B. Similarities between these nine external reasons for challenges and findings from prior studies by other researchers are commented on.

The nine external reasons for the challenges identified are:

1. *Legislation affecting the company*

is a reason mentioned for CA10, 11 and 12. In this case it relates mainly to the REACH:2006 legislation. Legislation is also an indirect reason for CA3, 6 and 7, see Paper II. The value 21% on the Y-axis in Figure 10 should therefore be viewed as a minimum value. Consequently, legislation affecting the company should be viewed as the most common external reason for the challenges at Company A. More specifically, complying with legislation is complex and requires resources (time, money, etc.) and a range of specific knowledge. It is therefore challenging for Company A to include environmental aspects that are inherited from legislation. However, legislation can also be a driver that supports inclusion of environmental aspects in product development (Bey et al., 2013). Therefore, legislation affecting the company shall be seen as a reason for the challenges, but not as a barrier for inclusion of sustainability aspects in product development.

2. *Economic reason at the supplier,*

is a reason mentioned for CA1, 4 and 13. *Economic reason at the supplier* is mostly about the supplier thinking that the *efforts* to fulfil Company A's sustainability requirements, and other requests, are too big compared with the *efforts'* return on investment. In other words, the return on investment for the more sustainable initiative is too small. Compare this with the internal reason for a challenge "*initiatives other than the more sustainable initiatives, contribute more efficiently to the economic goals*", described in subchapter 6.1 Internal reasons for challenges. This external reason is considered to have similarities with, or being similar to:

- "*Current/future locked-in situations or lack of bargaining power against other players*", a barrier identified by Stewart et al. (2016).
- "... 'we always look for the most environmentally friendly components. But, let's face it. We are not a giant company. We can't ask suppliers, sometimes ten times bigger than we are, to develop specific components.' ... ", stated by a respondent at a Swedish manufacturing company studied by Jönbrink and Melin (2008).

3. *Economic reason at the customer,*

is a reason mentioned for CB7. The economic reason is that the customer thinks the economic risk of buying the new, more energy efficient product, is too high. Mainly due to the perception that the new technology lacks dependability. This external reason is considered to have similarities with:

- “*Lack of market demand/willingness to pay*”, a barrier identified by Stewart et al. (2016).

4. *Lack of knowledge (and/or awareness) at the customer,*

is a reason mentioned for CB7. This relates to customers lacking the knowledge and/or awareness about the dependability and performance of new technology and that it is difficult to convince them. This external reason is considered as being similar to:

- “*Lack of understanding/knowledge among customers*” and has similarities with “*Lack of influence on customers*”, both “*barriers*” identified by Stewart et al. (2016).

5. *Lack of knowledge and/or awareness at the supplier,*

is a reason mentioned for CA2 and CA14. In CA2 it relates to a lack of knowledge on how to manage the restriction of chemicals or substances for a whole supply chain. In CA14 it relates to a lack of awareness that the supplier has to increase its own knowledge about environmental requirements and environmental legislation. This external reason is considered as being similar to:

- “*Lack of understanding/knowledge*”, identified by Stewart et al. (2016). Stewart et al. (2016) point out that this “*barrier*” is related to the supply chain.

6. *Legislation affecting the supplier,*

is a reason mentioned for CA5. In this case it relates to the REACH:2006 legislation, which is challenging to comply with for Company A’s suppliers.

7. *Lack of legislation affecting the supplier,*

is a reason for CA1. This reason relates to the lack of legislation that would force the supplier to share information about the material content in their products. This external reason has similarities with:

- “*Not enough legislative incentives*”, which is an “*obstacle*” described by Boks (2006). However, Boks does not state that it is the supplier specifically that is affected by this “*obstacle*”.

8. *Lack of available external data,*

is a reason mentioned for CA1. Even though the supplier’s customer requests certain data, the data may not yet have been collected and compiled by the supplier and therefore cannot be shared. The data is not available. This external reason is considered as being similar to:

- “*Difficulties in finding information on environmental impact*”, a “*barrier*” identified by Bey et al. (2013).

9. *Organizational issues at the supplier,*

is a reason mentioned for CA14. Persons with important knowledge at the supplier are for some reason not involved in business negotiations with its customers. This external reason is considered as having similarities with:

- “*Organizational complexities, lack of appropriate infrastructure*” and “*lack of cooperation between departments*”, which are “*obstacles*” identified by Boks (2006). However, Boks (2006) does not specifically say that these two “*obstacles*” affect the suppliers. On the other hand, Boks (2006) also identified “*...supply chain problems*”.

A summary of the nine main external reasons for challenges, and how commonly they cause the challenges identified at Companies A and B, is shown in Figure 10

None of these nine external reasons for challenges were mentioned by both case companies; therefore, none of the nine external reasons for challenges are *common* across the case companies.

Seven of the nine external reasons for challenges identified at Companies A and B (numbers 2, 3, 4, 5, 7, 8 and 9) are in line with barriers and obstacles identified in prior studies. The implication of that finding is that there are barriers and obstacles

that act as reasons for challenges that manufacturing companies can face when including sustainability aspects in product development.

Figure 10 The nine main internal reasons for challenges, and how commonly they cause the challenges identified at Companies A and B. The Y-axis presents the share (measured in %) of challenges at each company that are caused by each external reason. The external reasons are shown on the X-axis.

Two of the nine external reasons for challenges identified at Companies A and B (numbers 1 and 6) are not identified as reasons for challenges, or barriers (or some other term synonymous with *barrier*) in the prior studies covered in this thesis. They may therefore be novel findings that expand current knowledge of reasons for challenges that manufacturing companies can face when including sustainability aspects in product development.

7 CONCLUSIONS

This chapter presents a summary of how the aim of the thesis is fulfilled as well as summaries of the answers to each of the three questions.

This thesis expands current knowledge on how sustainability aspects are included in product development at large manufacturing companies, which challenges they may face, and the reasons why the manufacturing companies may face these challenges.

To expand current knowledge a literature study was conducted followed by a multiple case study at two international, listed, business-to-business, manufacturing companies in Sweden. In the multiple case study, the main data collection methods were semi-structured interviews with two selected respondents at each company, and analysis of the companies' latest sustainability reports. The two case companies were compared with each other, as well as with descriptions in the literature of other manufacturing companies. How the companies include sustainability aspects in product development, which challenges they face, and what is causing the challenges, were compared. The knowledge is expanded along the results of answering three research questions. Next follows summaries of the answers to the three research questions.

RQ1: How do manufacturing companies include sustainability aspects in their product development?

The findings described in this thesis strongly indicate that:

1. Whether designers consider social aspects when developing and designing a product depends on what is defined as a social aspect. For example, product safety, which can be seen as a social aspect, is considered by designers and system safety engineers at the case companies.
2. The more easily an aspect (for example, a sustainability 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. This may explain why social and environmental aspects of the product that are affected mainly by the supplier, such as *no forced labor*, are seldom, or never, considered by designers.

3. A company's *product owner* is a key actor for the inclusion of sustainability aspects in product development, and in particular for their inclusion in product requirements.
4. No need has been identified at the case companies to classify *no corruption*, or any other business ethical aspect, in the triple bottom lines: environmental, social and economic aspects. The triple bottom lines (Elkington, 1999) is an overall metaphor of sustainability rather than a categorization applied in product development practice to categorize sustainability aspects.
5. The timing when sustainability aspects are included in the product development process differs between manufacturing companies; for example, between the planning and the concept development phase. However, any statement that inclusion of sustainability aspects is done late or early in the product development process is influenced by what is considered to be the scope of the product development project.
6. There are manufacturing companies that include sustainability aspects in product development activities in a systematic manner. However, *what* activities the companies do in a systematic manner, and *how* these activities are performed in detail, differ between companies. The case companies are two such companies.
7. There are manufacturing companies that include sustainability aspects in their standard product development process, i.e., the companies do not use a separate product development process in which sustainability aspects are included. The case companies are two such companies.
8. Manufacturing companies focus on sustainability aspects that reduce the companies' economic risk and create economic opportunities.
9. The case companies view sustainability aspects mainly as environmental and social aspects. Economic aspects are a prerequisite for the inclusion of any aspect, including environmental and social aspects. Economy is the lens through which environmental and social aspects are viewed.
10. *Phasing out hazardous substances* and *reducing energy consumption from products' use phase* are examples of environmental aspects that are found relevant by manufacturing companies when they develop products.
11. Social aspects are mainly referred to as health and safety in the case companies' workplaces, and as health and safety, no forced labor, and no child labor in the supply chain.
12. Product safety can be seen as a social aspect but is not described as a social aspect by the case companies.
13. *Profit* and *return on investment* are two economic aspects considered and found important by manufacturing companies.

14. Inclusion of sustainability aspects in product development is a matter for many internal actors, not solely for designers and the product development function.
15. There are circumstances in which a Life Cycle Assessment (LCA) does not have to be conducted within a product development project for it to be found useful for that product development project. The knowledge and understanding achieved from LCAs conducted prior to the product development project can be useful enough.
16. The case companies have customized their methods to make them useful; this is similar to what other manufacturing companies do.

Additionally, the findings indicate that:

17. Conventional engineering methods applied by manufacturing companies can support the inclusion of sustainability aspects in product development. However, these methods are seldom referred to as ecodesign methods or methods aimed at developing products that are more sustainable. The role of conventional methods when including sustainability aspects in product development has been largely ignored in prior research.
18. At the case companies, marketing and sales do not systematically search for sustainability aspects that are important for customers.
19. A weak sustainability perspective is applied by the case companies.
20. At the case companies, goals for the inclusion of sustainability aspects in product development are applied mainly at a strategic level, rather than to *all* product development projects.

Answers numbers 1-5, 17 and 18 to RQ1 in the list above are considered to be the most novel contributions to RQ1. This is due to either (1) little has yet been written about the topics in the conclusion or (2) the conclusion contrasts with findings from prior studies.

RQ2: Which challenges do manufacturing companies face when including sustainability aspects in their product development?

An overall description of which challenges (including barriers) that manufacturing companies can face when including sustainability aspects in product development is considered to be well represented by the updated framework of Dekoninck et al. (2016) (Appendix B) and by the list of barriers in Stewart et al. (2016). Real-life examples of challenges are described in Paper III and a context to these challenges is included in Papers I and III. The real-life examples complement the overall descriptions of challenges and barriers by Dekoninck et al. (2016) and Stewart et al. (2016).

The contribution from this thesis to the answer of RQ2, are the 20 unique challenges described (of a total of 21 challenges) that are faced by two large manufacturing companies when including sustainability aspects in product development. A company context is described for the challenges (Papers I and III). Additionally, information about who face each challenge is described for most of the challenges identified.

A second contribution from this thesis, regarding the answer to RQ2, is the following three challenges that are proposed to be added to the comprehensive compilation of challenges described in the framework by Dekoninck et al. (2016).

1. *Making suppliers fulfil the sustainability requirements that are placed on them.*
2. *Transforming sustainability aspects, or general goals, into measurable requirements that contribute to reduced environmental impact from products while at the same time contributing to competitive profit.*
3. *Identifying how to reach economic goals more efficiently with a more sustainable initiative or solution than other initiatives.*

The updated framework of Dekoninck et al. (2016), which includes these three challenges, is described in Appendix B.

RQ3: Why do manufacturing companies face challenges when including sustainability aspects in product development?

Five internal reasons for challenges that manufacturing companies can face when including sustainability aspects in product development were identified. The following four of these five internal reasons have similarities with challenges and barriers identified in prior research by other researchers, and are therefore in line with their findings:

- *Lack of relevant knowledge (and/or awareness) in the company.*
- *Addressing the challenge is too complex and resource demanding (money, time and manpower) for the company.*
- *Initiatives other than the more sustainable initiatives, contribute more efficiently to the economic goals.*
- *Functional requirements are most important and must be fulfilled.*

One novel internal reason for challenges has been identified that expands current knowledge on internal reasons for challenges that manufacturing companies can

face when including sustainability aspects in product development. The novel reason for a challenge is:

- *Personal values/ beliefs about what is sustainable is not in line with the company's activities*

Nine **external reasons** for challenges that manufacturing companies can face when including sustainability aspects in product development were identified. The following *seven* of these nine identified external reasons for the challenges were found to be similar to (and therefore in line with) external barriers and obstacles identified in prior research by other researchers:

- *Economic reason at the customer*
- *Lack of knowledge (and/or awareness) at the customer*
- *Lack of available external data*
- *Economic reason at the supplier*
- *Lack of knowledge and/or awareness at the supplier*
- *Lack of legislation affecting the supplier*
- *Organizational issues at the supplier*

The following *two* of these nine identified external reasons for the challenges were not found in prior studies by other researchers. Thus, current knowledge on external reasons for challenges that manufacturing companies can face when including sustainability aspects in product development is expanded.

- *Legislation affecting the company*
- *Legislation affecting the supplier*

Which challenges that are caused by each of these internal and external reason for challenges are described in chapter 6 Reasons for challenges.

In addition to these identified reasons for challenges, a barrier can be seen as a reason for a challenge. Therefore, to acquire an overview of additional possible reasons for challenges that manufacturing companies can face when including sustainability aspects in product development, one must also study the barriers described by Stewart et al. (2016).

8 FINAL DISCUSSION

This chapter includes a discussion of the methodological implications of the results, the ethical implications of the research, the contribution to academia and industry, and suggestions for future research.

8.1 METHODOLOGICAL IMPLICATIONS OF THE RESULT

A substantial part of the data that serves as a base for the answers to the research questions comes from the four respondents, rather than the sustainability reports. The data therefore reflects mainly the respondents' perspectives of how the companies include sustainability aspects in product development; the challenges the companies face when doing so; and the reasons why the companies face these challenges. For example, in the descriptions of which challenges the companies face and who face each challenge, several of the challenges are faced by the respondents, or by the organizational function the respondents work in. The author finds it reasonable that other actors at the companies could face other challenges, but also the same challenges (e.g., both RA1 and RA2 face CA10 in Paper III). Additionally, the causal relationships between the *challenges* and the *reasons for the challenges* at Companies A and B depend on the respondents' perspective and each company's specific situation. Consequently, other actors could probably describe other or additional reasons for the challenges.

When selecting respondents, the idea was that the *companies* should select respondents who could best answer the interview questions. This idea was based on the view that companies know better than the author *who* can answer the interview questions best. However, it was *hoped* that the companies would have selected a designer, in addition to the respondents selected, to get an additional perspective. Which challenges, methods, reasons for challenges, etc., would have been mentioned by a mechanical designer, or a product owner?

Additionally, two respondents at each company is considered too few for the empirical data to be valid for a larger number of employees at each company, and the perspectives of the respondents are not necessarily the most important for other employees. Even though the perspectives of the respondents clearly affect the findings, the empirical data from the interviews is however considered to be one (but not the only) valid representation of the *companies*, because the respondents

selected are considered to be well informed and experienced in the topics of the interview.

The sustainability reports provided a business context for sustainability. For example, complementing data on what sustainability means for the companies, rather than data about how the companies work. No challenges and reasons for challenges were described in the sustainability reports. The sustainability reports are considered to mainly represent the perspective of the employees who decide what to communicate externally about the companies' contributions to sustainability. For this reason, to achieve high construct validity, the data from the sustainability report was selected carefully. The data in the sustainability reports complements, rather than tests, the perspective of the respondents. Only a minor part of the data in the case study comes from the sustainability reports.

The two case companies are international, listed, business-to-business, manufacturing companies located in Sweden. Both companies argue that their business contributes to sustainability. However, the impression is that Company B communicates its contribution to sustainability more than Company A. One may view Companies A and B as representatives for listed, manufacturing companies that have thought about sustainability aspects, identified economic risks and opportunities regarding sustainability aspects, and acted on several of these identified sustainability risks and opportunities.

Two manufacturing companies are too few to be considered as representative for a larger population of companies. Instead, the main values of studying the two companies are: (1) testing descriptions and findings from prior studies; (2) providing two context-dependent examples of how international, manufacturing companies include sustainability aspects in their product development, the challenges they face when doing so, and the reasons why they face the challenges.

The respondents at Company A were mainly responsible for environmental issues and they clearly mentioned that this is what they know most about. However, the answers they have given include social and economic aspects too. Social aspects generated the least information. Additional information about economic, and in particular social aspects, may therefore be revealed from Company A.

One of the respondents at Company B was responsible for Environment, Safety and Health aspects, and during the last eight years was also responsible for sustainability aspects. The other respondent was responsible for product development with no specific bias towards any specific sustainability aspect. No

obvious bias from the respondents towards environmental, social or economic aspects is identified. However, environmental aspects were most discussed during the interviews, perhaps because of the alignment of cutting costs for customers, with increased rate of energy efficiency of the products' use phase. The empirical data from Company B should therefore be interpreted as mainly neutral but with a small bias towards environmental aspects.

In the document used to invite the companies to participate in the study, the visual description of the Triple Bottom Line, as described by Wu (2013) (right picture in Figure 5), was used as a description of sustainability. That description might have influenced the respondents to classify and think of sustainability aspects more in terms of *environmental*, *social* and *economic* categories than if that description would not have been used. However, the bias from the description is expected to be low since the respondents did not adhere to it. For example, product safety was not categorised in any of the triple bottom lines. Moreover, the interview questions focused on the *companies'* view on sustainability.

Most respondents have a managerial position (RA1, RB1 and RB2). One may therefore expect the empirical data to be biased towards a managerial perspective. For example, why do the goals for product development projects apply mainly at a strategic level rather than to products or product development projects? However, two of the respondents (RA2 and RB2) have experience from working in product development projects and solving issues related to the design of products. RB2 has even worked as a designer. RA2 and RB2 are therefore expected to have enough insight from product development to balance the potential bias towards a managerial perspective. Additionally, the empirical data from RA2 and RB2 were in line with the empirical data from the other two respondents.

The findings from the literature study (Paper II) are to be understood as the result of a novel way of categorizing challenges described in prior studies by other researchers. The result is biased by how the author of this thesis interpreted the challenges described in prior studies.

In Paper III the word *challenge* has been collectively used for challenges, barriers (or other synonymous words). In Paper III, challenges and barriers (or other synonymous words) have been treated separately but denominated as challenges. In this thesis, a greater distinction has been made between challenges and barriers. The implication is that one should view the results as being focused on challenges but that any differences between challenges and barriers (with synonyms) have

been acknowledged. In the text this is acknowledged by frequently referring to the word (e.g., barrier) used by the authors of the prior studies.

When the details of the challenges faced by Companies A and B are considered, all but two challenges are considered unique. Is this surprising? Because semi-structured interviews with open questions about the challenges the companies face were used, the author believes it is not surprising, and that most challenges revealed therefore should be unique. The open questions catch the perspective of each respondent. In addition, due to the different responsibilities of each respondent and because the companies develop different products, different challenges are expected.

The reasons for challenges are described in the case descriptions in Paper III. Those reasons that were similar were aggregated into one rephrased version of the reasons (which represented all reasons in that group). The aggregation was performed by the author and the result of the aggregation, i.e., the reasons for challenges described in subchapter 6, is biased by how the author interpreted the respondents' descriptions of the reasons for each challenge. For example, a *too low economic risk* may be part of the reasons for CB3 and the *strive to minimize economic risk* is part of the reasons for CA13. However, these two reasons for challenges are excluded from further analysis because the author considers that the links between them and their corresponding challenge are too weak. In this thesis, one can follow and verify the aggregation of reasons for challenges made by the author. That can be done by comparing challenges (including the reasons for each challenge) described in Paper III with the links described between the challenges, and reasons for challenges, in subchapters 6.1 Internal reasons for challenges and 6.2 External reasons for challenges.

Ultimate root causes of the challenges have most probably *not* been identified, if they exist at all. The argument is that the respondents would probably have been able to keep elaborate on reasons for the challenges if the author of this licentiate thesis had probed each interview questions more deeply, and had not moved on to the next interview question.

8.1.1 ON THE USE OF VOICE AND VIDEO RECORDINGS DURING THE INTERVIEWS

During all interviews the respondents had a paper and a pen in front of them to draw sketches that supported their descriptions and explanations. The sketches were helpful in understanding what the respondents wanted to describe and explain. For example, Figures 1 and 2 in Paper I are based on the respondents' sketches.

However, it is difficult to remember what was said while the respondent sketched a certain detail of the sketch, and to remember in what order the sketch was built up. Video recording the paper and the hands of the respondent (nothing else) while sketching, together with a voice recording, solved this problem. The quality of the *interpretation* (by the author of this thesis) of the sketch was considered to be higher when watching the video while listening to the respondent, compared to only looking at the stored and completed description. Since this methodology does not focus on the respondent's face, this methodology is recommended in situations where a visual description is useful and when the integrity of the respondent is important. However, video recordings were only made for half of the interviews due to restrictions at one of the companies, and the restriction was only revealed when starting the interview.

8.2 ETHICAL IMPLICATIONS

The research described in this thesis is motivated by, among other things, that the outcome shall contribute to sustainable development by reducing the risk of harm to people and the environment from the development, manufacture, use, maintenance, reuse, disposal (i.e., a product's entire life cycle) of products. According to ALLEA (2017), it is good research practice for researchers to "*recognise and manage potential harms and risks relating to their research*". Moreover, The National Committee for Research Ethics in Science and Technology (2008) states that the researcher shall "... *indicate any elements of risk or uncertainty that may be significant for possible uses of the research results*". Gustafsson et al. (1984) state that the researcher shall reflect upon whether the research outcome can be used for warfare, damage the environment or undermine human rights. No obvious risk of using the outcome of the research for warfare and to harm people and the environment is identified, nor for undermining human rights, rather the opposite.

There was no formal ethical review of the research project when it started, nor was there an ethical review during the research project. However; the requirements for review of research projects by an ethical review board (Swedish Research Council, 2011) are not considered met, because the most critical personal data of name, position at the company and experience, and gender and name are not documented. The respondents gave informed consent to use the data given; however, they wanted to be anonymous and that there should be no obvious way for the reader to identify the companies they work for.

The major ethical risk is considered to be the management and safe preservation of empirical data (to ensure the integrity of the respondents), while fulfilling requirements for being able to scrutinize the research conducted. This is achieved by omitting to publish the names of the companies and by describing the companies in a way that they are not easily identified. For example, the companies' products, business areas and customers are not described. The descriptions of the companies are however considered sufficiently informative to expand knowledge and be valuable for future research.

8.3 CONTRIBUTIONS TO ACADEMIA

The research in this thesis contributes to academia with:

- expansion of current knowledge on *how* manufacturing companies include sustainability aspects in product development, in real life (see Chapter 4 Sustainability aspects in product development, and Paper I)
- industrial perspectives on the inclusion of sustainability aspects in product development and what constitutes a sustainability aspect (see subchapter 4.3 Sustainability aspects, and Paper I)
- increased knowledge on which *challenges* manufacturing companies can face when including sustainability aspects in product development and *reasons why* manufacturing companies may face these challenges (see Chapter 5 Challenges, Chapter 6 Reasons for challenges, and Paper III)
- findings showing that a systems perspective should be more present than today in research and other activities (see subchapter 5.1 Challenges within ecodesign, and Paper II)
- an update of the comprehensive framework of challenges by Dekoninck et al. (2016), which makes the framework even more comprehensive and useful. The updated framework is shown in Appendix B.
- findings that contribute to filling the gap in reports that describe the diffusion of ecodesign tools in product development, identified by Baumann et al. (2002)
- findings that cover sustainability aspects, rather than environmental aspects only (covering environmental aspects only has been common in prior research)
- two context-dependent examples of how manufacturing companies include sustainability aspects in product development, which challenges they face, and what is causing the challenges. The two context-dependent examples are described in Papers I and III and complement prior prescriptive research that describes how manufacturing companies *could*, or *should*, work.

8.4 CONTRIBUTIONS TO INDUSTRY

The two cases increase the understanding of how listed, manufacturing companies (in particular international, listed, business-to-business manufacturing companies in Sweden) look at sustainability and how they include sustainability aspects in their product development.

The knowledge on challenges and reasons for challenges that manufacturing companies can face when including sustainability aspects in product development, supports other manufacturing companies in identifying risks and opportunities relating to their *own* business strategies, product plans, product development projects and other initiatives.

8.5 FUTURE RESEARCH

Proposed areas for research:

1. *How product owners elicit and prioritize sustainability aspects*, and how these aspects are formulated in early product requirements.

Research within this area would reveal an understanding of how *product owners* (and important actors in the requirements development process) work. That understanding will enhance the possibility to identify concrete areas for improvements concerning the inclusion of sustainability related requirements in product specifications. Research within this area will also enhance the understanding of how the sustainability aspects identified influence which product development projects will be run. This suggestion for future research is backed by Lee-Mortimer and Short (2009) who suggest more research on how the companies' product specification process can be improved. The suggestion is also in line with the future research in "*green product portfolio management*", suggested by Dangelico and Pujari (2010).

2. *How, and how commonly, marketing and sales elicit sustainability aspects from customers.*

Research within this area would enhance knowledge of how actors that commonly meet customers elicit sustainability aspects from customers, and could preferably be performed at best-practicing companies. The studies would contribute with suggestions on how to increase the chances of identifying sustainability aspects that are important for customers, and consequently would increase the chances that sustainability aspects are considered when product requirements are developed.

3. Conduct more explanatory research

Explanatory research would complement earlier research within the areas of ecodesign and similar approaches that study the inclusion of sustainability aspects in product development, which are mainly exploratory and descriptive. For example, more explanatory studies could increase the knowledge on why actors in companies take the decisions that they do. In particular, decisions that affect environmental sustainability. Such studies would contribute with causal relationships between daily decisions in the companies related to environmental sustainability, and a deeper understanding of why these decisions were taken.

Additionally, the author agrees with the suggestion by Isil and Hernke (2017), to study the implications of *strong sustainability* and “*planetary sustainability*” on how companies consider and work with sustainability.

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APPENDIX A – ORIGINAL FRAMEWORK OF CHALLENGES

Appendix A presents a copy of the framework developed by Dekoninck et al. (2016), which describes challenges that manufacturing companies can face when implementing ecodesign.

Table 1 The framework of challenges that manufacturing companies can face when implementing ecodesign, adapted from Dekoninck et al. (2016).

FRAMEWORK		
Category	Theme	Subheading
1. Strategy	1.1 Building the business case and gaining senior management commitment	1.1.1 Identifying the business drivers
		1.1.2 Lack of senior management commitment/support
	1.2 Developing a long-term strategy	1.2.1 Developing and updating strategy over time
		1.2.2 Poor integration into management and corporate strategy
		1.2.3 Lacking effective prioritization process to ensure the projects that will deliver the greatest business value and environmental benefit are implemented
		1.2.4 Difficult to keep the momentum for ecodesign implementation
2. Tools	2.1 Finding the right tool for ecodesign implementation	2.1.1 Lack of criteria for selecting the most suitable tools
		2.1.2 Difficult to implement new tools within the development process
		2.1.3 Need for new tools
	2.2 Problems with applying existing tools	2.2.1 Difficult to use the results of an LCA to inform the decision-making process
		2.2.2 Completing an LCA requires too much resource in terms of data, time, and expertise
		2.2.3 Support for data exchange between different tools is lacking
		2.2.4. Difficult to achieve the behavior and cultural changes necessary to support tool implementation

		2.2.5 Difficult to find the right balance between simplification of the LCA approach and potential loss of accuracy/reliability/quality
3. Collaboration	3.1 Internal Collaboration	3.1.1 Need for multidisciplinary and multi-department approach
		3.1.2 Difficult to use ecodesign knowledge to support decision making across different functions
		3.1.3 Difficult to involve key stakeholders in the early stage to create trust and ownership
		3.1.4 Difficult to raise internal awareness for ecodesign implementation
		3.1.5 Responsibility for ensuring that ecodesign objectives are achieved is not clearly allocated to individuals/teams
	3.2 External Collaboration	3.2.1 Identifying the stakeholders from the value chain to include in the eco-design effort
		3.2.2 Changing the type of interaction in the value chain from transactions to collaborations
		3.2.3 Difficult to raise external awareness for ecodesign implementation
		3.2.4 Transparency of environmental data in the value chain
4. Management	4.1. Integration with New Product Development	4.1.1 Difficult to integrate ecodesign activities into the product development process
		4.1.2 Difficult to manage expectations within development projects
		4.1.3 Lack of a systematic approach to the implementation of ecodesign throughout the company
		4.1.4 Lack of deployment of roadmap for continuous improvement
		4.1.5 Difficulty to integrate environmental issues very early in the development process
		4.1.6 Lack of environmental impacts as a global target
		4.1.7 Lack of motivation/resistance from internal stakeholders for ecodesign
		4.1.8 Problems fitting with timescales of NPD process
	4.2. Managing requirements	4.2.1 Difficult to take decision when there are trade-offs between environmental issues and the other aspects (such as cost, quality, security...)
		4.2.2 Difficult to manage customers' requirements for ecodesign
	4.3. Resource allocation	4.3.1 No extra resources allocated to new ecodesign initiatives
		4.3.2 No extra time allocated to new ecodesign initiatives
	4.4. Organisation and structure	4.4.1 Difficult to know which department should house the ecodesign implementation activity
		4.4.2 Difficult to implement new business models
5. Knowledge	5.1. New knowledge and expertise need to be developed in the company	5.1.1 Communication among people with different expertise is difficult
		5.1.2 Requires a large amount of knowledge development both within the design department and the supporting business functions
		5.1.3 Staff do not have the level of environmental knowledge required for effective ecodesign

	5.2. New types of data required	5.2.1 Difficult to find the environmental impact data required for ecodesign
		5.2.2 Difficult to find alternative materials/components that would have a lower environmental impact

APPENDIX B – UPDATED FRAMEWORK OF CHALLENGES

Appendix B presents the proposed update of the framework of challenges described by Dekoninck et al. (2016).

Tabell 1 Challenges for implementation of ecodesign in manufacturing companies. This table is a proposed update of the framework developed by Dekoninck et al. (2016). Challenges in grey fields are the contributions from Paulson and Sundin (2019) (Paper III). The original framework is shown in Appendix A and does not include the challenges in the grey fields.

FRAMEWORK		
Category	Theme	Subheading
1. Strategy	1.1 Building the business case and gaining senior management commitment	1.1.1 Identifying the business drivers
		1.1.2 Lack of senior management commitment/support
		1.1.3 Identifying how to reach economic goals more efficiently with a more sustainable initiative or solution than other initiatives
	1.2 Developing a long term strategy	1.2.1 Developing and updating strategy over time
		1.2.2 Poor integration into management and corporate strategy
		1.2.3 Lacking effective prioritization process to ensure the projects that will deliver the greatest business value and environmental benefit are implemented
		1.2.4 Difficult to keep the momentum for ecodesign implementation
2. Tools	2.1 Finding the right tool for ecodesign implementation	2.1.1 Lack of criteria for selecting the most suitable tools
		2.1.2 Difficult to implement new tools within the development process
		2.1.3 Need for new tools
	2.2 Problems with applying existing tools	2.2.1 Difficult to use the results of an LCA to inform the decision-making process

		2.2.2 Completing an LCA requires too much resource in terms of data, time, and expertise
		2.2.3 Support for data exchange between different tools is lacking
		2.2.4. Difficult to achieve the behaviour and cultural changes necessary to support tool implementation
		2.2.5 Difficult to find the right balance between simplification of the LCA approach and potential loss of accuracy/reliability/quality
3. Collaboration	3.1 Internal Collaboration	3.1.1 Need for multidisciplinary and multi-department approach
		3.1.2 Difficult to use ecodesign knowledge to support decision making across different functions
		3.1.3 Difficult to involve key stakeholders in the early stage to create trust and ownership
		3.1.4 Difficult to raise internal awareness for ecodesign implementation
		3.1.5 Responsibility for ensuring that ecodesign objectives are achieved is not clearly allocated to individuals/teams
	3.2 External Collaboration	3.2.1 Identifying the stakeholders from the value chain to include in the eco-design effort
		3.2.2 Changing the type of interaction in the value chain from transactions to collaborations
		3.2.3 Difficult to raise external awareness for ecodesign implementation
		3.2.4 Transparency of environmental data in the value chain
		3.2.5 Making suppliers fulfil the sustainability requirements that are placed on them
4. Management	4.1. Integration with New Product Development	4.1.1 Difficult to integrate ecodesign activities into the product development process
		4.1.2 Difficult to manage expectations within development projects
		4.1.3 Lack of a systematic approach to the implementation of ecodesign throughout the company
		4.1.4 Lack of deployment of roadmap for continuous improvement
		4.1.5 Difficulty to integrate environmental issues very early in the development process
		4.1.6 Lack of environmental impacts as a global target
		4.1.7 Lack of motivation/resistance from internal stakeholders for ecodesign
		4.1.8 Problems fitting with timescales of NPD process

		4.1.9 Transforming sustainability aspects, or general goals, into measurable requirements that contribute to reduced environmental impact from products while at the same time contributing to competitive profit.
	4.2. Managing requirements	4.2.1 Difficult to take decision when there are trade-offs between environmental issues and the other aspects (such as cost, quality, security)
		4.2.2 Difficult to manage customers' requirements for ecodesign
	4.3. Resource allocation	4.3.1 No extra resources allocated to new ecodesign initiatives
		4.3.2 No extra time allocated to new ecodesign initiatives
	4.4. Organisation and structure	4.4.1 Difficult to know which department should house the ecodesign implementation activity
		4.4.2 Difficult to implement new business models
	5. Knowledge	
		5.1. New knowledge and expertise need to be developed in the company
		5.1.1 Communication among people with different expertise is difficult
		5.1.2 Requires a large amount of knowledge development both within the design department and the supporting business functions
		5.1.3 Staff do not have the level of environmental knowledge required for effective ecodesign
	5.2. New types of data required	5.2.1 Difficult to find the environmental impact data required for ecodesign
		5.2.2 Difficult to find alternative materials/components that would have a lower environmental impact

APPENDIX C – CHALLENGES AND BARRIERS IN PRIOR STUDIES

Examples of challenges and barriers identified in prior empirical studies by other researchers. The list of examples of challenges and barriers in this Appendix is compiled by the author of this thesis. The list serves as a complement to challenges and barriers described in Appendix A and is only intended to give the reader more understanding of what a challenge or barrier that manufacturing companies can face when including sustainability aspects in product development, may be.

The challenges and barriers are categorized into:

1. Barriers and challenges relating to the business objective and strategy
2. Barriers and challenges relating to collaboration and the supply chain
3. Barriers relating to lack of resources (time, money and manpower)
4. Barriers and challenges relating to lack of and access to information and knowledge
5. Barriers relating to legislation
6. Barriers and challenges relating to a lack of sustainability requirements
7. Barriers and challenges relating to management and product development in general
8. Examples of barriers for adoption of ecodesign methods

Note: the barriers described by Jönbrink et al. (2013) are originally described in Swedish and have been translated into English by the author of this licentiate thesis.

1. Barriers and challenges relating to the business objective and strategy

- 1.1 “No apparent requirement from market or customers” is one of the main barriers for a company to include sustainability aspects in product development (Short et al., 2012). Similarly, no market demand is one of the main barriers for “... bringing ecodesign products to the market” (Boks, 2006).
- 1.2 Different status between “... environmental and traditional design requirements ...”, which tends to lead to less optimal solutions from an environmental perspective (Poulidikidou et al., 2014).

- 1.3 *“Cost is still the main driver in [New Product Development] activities and it is very difficult to implement an ecodesign solution that is not cost-effective”* (Dekoninck et al. (2016).
- 1.4 *“Lack of profit”*, is a barrier for companies to work with ecodesign, especially when business and environmental objectives are not aligned (Jönbrink et al., 2013).
- 1.5 Short-term economic perspective is a barrier for inclusion of environmental aspects in product development (Jönbrink et al., 2013). Similarly, *“costs and short-term economic thinking are perceived as the dominant barrier when making decisions regarding sustainability [in product development]”* (Schulte and Hallstedt, 2017a).
- 1.6 It is a challenge to optimize environmental and social aspects of a product’s entire life cycle, while at the same time being competitive (Hallstedt and Thompson, 2011).

2. Barriers and challenges relating to collaboration and the supply chain

- 2.1 *“Organisational complexities[/]lack of appropriate infrastructure”*; *“too big a gap between ...”* proponents and executors when it comes to inclusion of environmental aspects in product development; and *“lack of cooperation between departments [within the company]”*, are barriers for spreading information that relates to the inclusion of environmental aspects in product development (Boks, 2006).
- 2.2 Resistance from suppliers to provide information, for example information about material content in their products, is a barrier to efficient information collection, and to efficiently make the product comply with requirements that relate to environmental aspects (Poulikidou et al., 2014).
- 2.3 *“[To have] control over sustainability aspects throughout the whole supply chain is considered challenging”* when sustainability related decisions for the company’s products shall be made (Schulte and Hallstedt, 2017a).
- 2.4 It is *“difficult to raise internal awareness for ecodesign implementation”* (Dekoninck et al., 2016).
- 2.5 Choosing a design option that is supposed to reduce the environmental impact from a product can be hampered if the company perceives it is not the company’s responsibility to realize the design option (van Hemel and Cramer, 2002).

3. Barriers relating to lack of resources (time, money and manpower)

- 3.1 *“Lack of time and other resources”* are barriers for inclusion of environmental aspects in product development (Jönbrink et al., 2013).

- 3.2 “*Not enough time during product development*” was a common barrier for inclusion of sustainability aspects in product development in the study by Short et al. (2012).
- 3.3 “... *time and/or cost are ubiquitous barriers to environmental design beyond compliance: ...*” (Deutz et al., 2013).
- 3.4 Efficient implementation of ecodesign in the organization is limited by time constraints (Poulikidou et al., 2014).
- 3.5 Lack of allocated time is one of the “*main barriers for implementation of environmental strategies in [manufacturing] companies*” (Bey et al., 2013).
- 3.6 Complying with environmental standards and legislation and monitoring changing environmental legislation requires much money and manpower. (Poulikidou et al., 2014).
- 3.7 “*Initial expense*” was one of the most common barriers for inclusion of sustainability aspects in product development in the study by Short et al. (2012).
- 3.8 Lack of allocated manpower, is one of the “*main barriers for implementation of environmental strategies in [manufacturing] companies*” (Bey et al., 2013).

4. Barriers and challenges relating to lack of and access to information and knowledge

- 4.1 Lack of environmental impact information, is one of the “*main barriers for implementation of environmental strategies in [manufacturing] companies*” (Bey et al., 2013).
- 4.2 “... *designers are not aware of the environmental impact that result from the decisions they are making*”, which makes the implementation of ecodesign challenging (Dekoninck et al., 2016).
- 4.3 It is a challenge to make designers access information of component performance; for example, “*information ... collected during maintenance*”, which would support selling services rather than products (Hallstedt and Thompson, 2011).
- 4.4 Lack of own and customers’ knowledge are barriers for inclusion of environmental aspects in product development. The knowledge that is lacking varies; for example, some customers lack knowledge of LCC and many internal actors lack knowledge of how to include sustainability considerations in their own work (Jönbrink et al., 2013).
- 4.5 “*Lack of expert knowledge*” is one of the “*main barriers for implementation of environmental strategies in [manufacturing] companies*” (Bey et al., 2013).

- 4.6 Lack of good education on environmental aspects of the company's products is a barrier for inclusion of environmental aspects in product development (Poulidikou et al., 2014).
- 4.7 "... *lack of knowledge can be a barrier*" for making sustainability related decisions on a company's products. Two examples of knowledge that may be lacking are knowing how to assess sustainability of a design and an understanding of what sustainability means (Schulte and Hallstedt, 2017a).
- 4.8 "*Lack of awareness/understanding by designers & engineers*" can be a barrier for inclusion of sustainability aspects in product development (Short et al., 2012).

5. Barriers relating to legislation

- 5.1 Considering environmental aspects in design can be complex and time consuming due to unharmonized and constantly changing legislation (Poulidikou et al., 2014).
- 5.2 The large number of environmental "... *requirements and standards that need to be considered and balanced during design decisions*" in a limited amount of time, together with the complex nature of environmental requirements, are barriers for efficient inclusion of environmental aspects in product development (Poulidikou et al., 2014).

6. Barriers and challenges relating to a lack of sustainability requirements

- 6.1 "*No [sustainability] requirement in the product design specification*" can be a barrier for inclusion of sustainability aspects in product development (Short et al., 2012).
- 6.2 It is difficult to communicate environmental issues in technical terms familiar to designers (Poulidikou et al., 2014).
- 6.3 "*As sustainability is often hard to quantify and measure, there is a difficulty to translate such aspects into specific requirements that product developers can work with*" (Schulte and Hallstedt, 2017a).
- 6.4 It is a challenge to translate future requirements into concrete actions in the present and prioritize those actions (Schulte and Hallstedt, 2017a).
- 6.5 It is a challenge to turn strategic ambitions of sustainability into actions (Schulte and Hallstedt, 2017a).
- 6.6 There is a "... *lack of sustainability criteria*" that can be used, for example, to compare solutions from a sustainability point of view. This lack was the second most frequently described barrier for making sustainability related decisions on the companies' studied products (Schulte and Hallstedt, 2017a).

- 6.7 “*Lack of environmental goals and vision for individual development projects*” is one of the main barriers for “... *bringing ecodesign products to the market*” (Boks, 2006).

7. Barriers and challenges relating to management and product development in general

- 7.1 “*Lack of management commitment*” on sustainability aspects was perceived as a barrier for making sustainability related decisions on a company’s products by some of the companies studied by Schulte and Hallstedt (2017a).
- 7.2 Choosing a design option that is supposed to reduce the environmental impact from the product, for example, trying to use less packaging, can be hampered if there is “*no clear environmental benefit*” of that design option (van Hemel and Cramer, 2002).
- 7.3 Implementation of ecodesign is hampered by the difficulty to implement ecodesign methods in the product development process, because these methods are often used in later stages of the product development process and expert knowledge is often required (Dekoninck et al., 2016).
- 7.4 Choosing a design option that is supposed to reduce the environmental impact of the product, for example identifying and using a material for the product with low environmental impact, can be hampered if there is no such design option (material) available (van Hemel and Cramer, 2002).
- 7.5 It is a challenge to effectively implement and utilize “... *processes, responsibilities, information flows, available documentation and tools ...*” for environmental considerations in product development. This challenge leads to “... *time consuming processes ... and communication gaps*” (Poulikidou et al., 2014).
- 7.6 Focus on a single environmental aspect, such as energy efficiency, rather than having a comprehensive view, hampers the inclusion of environmental aspects in product development (Jönbrink et al., 2013).
- 7.7 It is a challenge to include social aspects in product development (Mesquita, 2016).

8. Examples of barriers for adoption of ecodesign methods

- 8.1 Time constraints (Lindahl, 2005; Rossi et al., 2016)
- 8.2 Cost of the method that does not justify the investment in the method (Lindahl, 2005; Rossi et al., 2016)
- 8.3 Large quantity of data required (Rossi et al., 2016)
- 8.4 Lack of environmental goals (Rossi et al., 2016)

- 8.5 Lack of knowledge and education ecodesign (Lindahl, 2005; Rossi et al., 2016)
- 8.6 Unnecessary complexity of a method (Lindahl, 2006; Rossi et al., 2016)
- 8.7 If the method is perceived by the user to not provide benefit and facilitate the work (Lindahl, 2006)
- 8.8 Implementing a new method can redirect the company's focus from the product to the method, which creates a risk for the company (Lindahl, 2006)
- 8.9 Large quantity of data required (Rossi et al., 2016)
- 8.10 Customization of methods is required for adoption in a company, but this requirement itself can be a barrier for the adoption (Knight and Jenkins, 2009)

APPENDIX D – INTERVIEW QUESTIONS

The relation between the interview questions, research questions and questions relating to the company context.

Table 1 presents the research questions and questions relating to the company context. These were the overall questions to be answered during the multiple case study. Table 1 is an expansion (to give more information) of four cells in the first row of Table 2.

Table 2 shows the interview questions and their relation to the research questions and questions relating to the company context. The grey fields show which questions are related. The purpose of making this relation between questions was to optimize the set of interview questions. Note: follow-up questions are not shown in Table 2, but were asked after conclusion of most of the interview questions.

Table 1 The research questions and questions relating to the company context.

RQ1: How do manufacturing companies include sustainability aspects in their product development?	Drivers: What are the main drivers for manufacturing companies to include sustainability aspects in their product development?	RQ2: Which challenges do manufacturing companies face when including sustainability aspects in their product development? RQ3: Why do manufacturing companies face challenges when including sustainability aspects in product development? (Answers to RQ3 come mainly from follow-up questions to the interview questions relating to RQ2, such as <i>why do you face this challenge?/why is this a challenge?</i>)	Support: What support needs do manufacturing companies have in regard to including sustainability aspects in product development?
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Table 2 Interview questions, and the relation between interview questions, research questions and questions regarding the company context.

	Interview questions	RQ1	Drivers	RQ2 and RQ3	Support
1	What are your main tasks at your work?				
2	Describe your experiences of these tasks				
3	What does sustainability mean for your company?				
4	On which sustainability-related aspects does your company focus its efforts?				
5	Why does your company work with sustainability?				
6	For which actors is sustainability important?				
7	Does your company include sustainability aspects in product development?				
8	How does the process look, when including sustainability aspects in product development?				
9	Which actors are involved when including sustainability aspects in product development?				
10	Which are the most important actors involved when including sustainability aspects in product development?				
11	What are the main drivers for your company to include sustainability aspects in product development?				
12	What measurable goals does your company have in regard to including sustainability aspects in product development?				
13	Which methods are used when including sustainability aspects in product development?				

14	Which methods are there requirements on using?				
15	Which challenges does your company face today when including sustainability aspects in product development?				
16	Which are the most important of these challenges to solve?				
17	Which challenges will your company face in the future when including sustainability aspects in product development?				
18	How would you like your company to include sustainability aspects in product development in the future?				
19	Why would you like your company to include sustainability aspects in product development like that in the future?				
20	If you could get any solutions to avoid/overcome each challenge, what would those solution do?				
21	How well does each method satisfy your requirements for them? Alt: How well do each of the methods satisfy your needs?				
22	Is there anything that you would like to add?				
23	Is there anything you think I should have asked you?				

Papers

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