THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Assessing Sustainability and Guiding Development towards More Sustainable Products

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ABSTRACT

Companies need to develop more sustainable products that fit into future more sustainable markets. For this reason, the integration of sustainability considerations is needed in the early stages of product development, where a major part of the sustainability performance of a final product is determined. The aim of the research presented in this doctoral thesis is to better understand both enablers and obstacles in developing sustainable products.

This research is based on three empirical studies. In the *first study* participatory action research was applied in a material research project aiming at developing wood-based materials to replace petroleum-based materials, while ensuring a more sustainable product. A specific focus was on how to facilitate action towards more sustainable products by visualising what affects a product's sustainability.

The insights from the first study were applied to the *second study*, an investigation of the connection between ecolabels and clothing design at three Swedish clothing companies. The research revealed a weak connection, because present ecolabel criteria mainly focus on considerations at the production stage.

During the above-mentioned studies it became increasingly apparent that the business organisation has an important influence on companies' ability to develop more sustainable products. A *third study* examined two companies to attain a better understanding of how company management systems affect work practices regarding sustainability in product development.

The research revealed that technical knowledge on products, production and sustainability is a necessary condition, but by itself not sufficient to drive development of more sustainable products; action competence in a broader sense is needed. For a company or organisation to achieve action competence, collaboration and team learning are necessary, since many different skills must be utilised.

Keywords: early-stage product development, participatory action research, sustainability assessment, wood-based material, ecolabels, role of designer, semi-structured interview, management systems, action competence, team learning

LIST OF INCLUDED PUBLICATIONS

This thesis is based on the work described in the following papers, which are referred to by Roman numerals in the text:

Paper I
Gunilla Clancy, Morgan Fröling & Magdalena Svanström (2013)
Changing from petroleum- to wood-based materials: Critical review of how product sustainability characteristics can be assessed and compared
Published in *Journal of Cleaner Production 39*, 372-385

Paper II
Gunilla Clancy, Morgan Fröling, Gregory M. Peters & Magdalena Svanström (2010)
Environmental challenges when developing renewable materials to replace non-renewable materials: Guidance from LCA studies
In proceedings of 9th International conference on EcoBalance 'Towards & Beyond 2020', 9-12 November 2010, Tokyo, Japan

Paper III
Gustav Sandin, Gunilla Clancy, Sara Heimersson, Gregory M. Peters, Magdalena Svanström & Marieke ten Hoeve (2014)
Making the most of LCA in inter-organisational R&D projects
Published in *Journal of Cleaner Production 70, 97-104*

Paper IV
Sverker Alänge, Gunilla Clancy & Magnus Marmgren (2014)
Naturalizing sustainability in product development: A comparative analysis of COMPANY A and COMPANY B
Manuscript

Paper V
Gunilla Clancy, Morgan Fröling & Gregory M. Peters (2013)
Ecolabels as drivers for clothing design
Submitted manuscript

Paper VI
Gunilla Clancy, Morgan Fröling & Magdalena Svanström (2013)
Insights from guiding material development towards more sustainable products
Published in *International Journal of Sustainable Design 2*(2), 149-166

Contributions of the author of the thesis to included papers

Paper I
Gunilla Clancy performed the literature study and the gap analysis was made together with the co-authors. She then wrote the paper with inspirational input from the co-authors.

Paper II
Gunilla Clancy proposed and performed the LCA estimates and analysed them together with co-author Morgan Fröling. She then wrote the major part of the paper with inspirational input from the co-authors.

Paper III
Gunilla Clancy contributed with experiences and reflections of her work with LCA in R&D projects as well as input to the writing of the paper.

Paper IV
Gunilla Clancy planned and performed the interviews together with the co-authors. She contributed with experiences and reflections as both insider and outsider researcher and coordinated the writing of the paper. The three authors' contribution in this paper is equal, in terms of designing the study, analysing, writing and developing the final paper.

Paper V
Gunilla Clancy performed a content analysis of ecolabels. She suggested and contacted the interviewees. She planned, organised, performed and analysed the interviews. She wrote the paper with inspirational input from the co-authors.

Paper VI
Gunilla Clancy planned, organised and carried out the workshops together with co-author Magdalena Svanström. Gunilla Clancy planned and performed the collection of data and the calculations. The analysis was performed together with the co-authors. She wrote the paper with inspirational input from the co-authors.

Other publications by the author related to the research in this thesis

Conference papers

Magnus Marmgren, Gunilla Clancy & Sverker Alänge (2013)
Management Systems' Influence on Sustainable Innovation: A Comparative Analysis of Two Large MNCs
Oral presentation performed by the main author at the 18th International Conference on Sustainable Innovation, 4-5 November 2013, Epsom, UK.

Gunilla Clancy, Morgan Fröling, Magdalena Svanström & Sverker Alänge (2013)
Actionable knowledge to develop more sustainable products
Oral presentation performed by the main author at the 6th International Conference on Life Cycle Management, Gothenburg, Sweden

Book chapter

Gunilla Clancy (2014)
Case IKEA: A small percentage with big impact
A chapter in the textbook *Sustainable Business Development: Frameworks for Idea Evaluation and Cases of Realized Ideas* Sverker Alänge and Mats Lundqvist (eds.), s. 190-194

Licentiate thesis

Gunilla Clancy (2012)
Guiding development of wood-based materials towards more sustainable products
Licentiate thesis, Chemical and Environmental Science, Chalmers University of Technology, Gothenburg, Sweden

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Gunilla Clancy

TABLE OF CONTENTS

1. INTRODUCTION

People, non-governmental organisations and society want more sustainable products. Companies want to develop more sustainable products. An obvious question may be: Who wants to develop unsustainable systems, processes or products? Yet most companies struggle with identifying relevant sustainability considerations, identifying trade-offs and how to act to in practice achieve more sustainable products.

1.1 Sustainability concerns and development of products

Demands on Earth's resources are increasing due to economic growth and population growth combined with the intensive use of energy and materials. To ensure that human needs are met in the long term requires the well-reasoned use and fair distribution of resources. At the same time, restrictions on resource use and on pollution are necessary to prevent harm to the ecosystem services that are vital for resource regrowth, for the purification of air and water, as well as for the regulation of climate and pests (MEA, 2005; TEEB, 2009).

In order to manage the limitation of resources and to meet greater demand, companies need to develop and offer more sustainable products, which is also necessary for companies to stay in business in the long term. Earlier studies have indicated that actions for reducing the negative sustainability impact of products preferably should start at the early product development stage, since many sustainability burdens of a product are determined through choices that are made at this stage, and at this stage, the cost of change is comparatively low (Baumann, Boons, & Bragd, 2002; Sakao & Fargnoli, 2010). How to make this happen is the topic of this thesis.

Developing more sustainable products involves many different considerations, such as impacts on the resource base, on climate and many other challenging aspects of human society, as well as global market issues, such as stakeholder interests, patents and policy instruments. The complexity of developing more sustainable products, thus, requires skills within many areas as well as a willingness to seek new opportunities. These skills and the willingness to learn and to change need to be developed or translated into the ability to act. Actionable knowledge (Argyris, 1996) is knowledge that informs us of how to create and integrate different skills into processes that will give us, in this case, more

sustainable products. It is, however, common to get stuck within a specific knowledge area or a work practice so that only new knowledge that can be seen as contributing to the development of *status quo* expertise or work practice is absorbed and used (Ansoff & McDonnell, 1990). In addition, companies have a tendency to make quality and sustainability staff functions do their job more 'in theory' instead of letting them have real 'in action' influence on value-adding processes in the organisations (Book, Alänge, & Solly, 2006).

One of the problems when going from theory to action is that *sustainable development* is a frequently used term in many different situations, such as in politics, in business strategies, in advertising and in other discussions. When politicians, scientists and company leaders are heard talking about sustainability, it is tempting to believe that sustainable development is a well-defined and established plan for a future sustainable society that everyone agrees on and is striving to implement. However, sustainable development is a multidimensional concept that is difficult to manage with a few key performance indicators or instructions. For this reason, companies need to work on describing sustainable development in relation to their own businesses and to formulate and integrate long-term strategies and visions for sustainability into their strategies.

Many analytical methods and tools exist for assessing the environmental life cycle performance of products based on one or several environmental parameters. These include Carbon Footprint (CF), Water Footprint (WF) and Life Cycle Assessment (LCA) (Finnveden & Moberg, 2005; Wrisberg, Udo de Haes, Triebswetter, Eder, & Clift, 2002). Methods and tools for assessing different or a broader scope of sustainability have also been developed, such as Life Cycle Costing, Social LCA and Life Cycle Sustainability Assessment (Finkbeiner, Schau, Lehmann, & Traverso, 2010). The selection of sustainability parameters is most often based on data availability, compliance with legislation or conventional concerns for the product or industry (Clancy, 2012). Whereas how to identify which sustainability parameters are relevant to assess in each particular case, and thereby determine which methods or tools are relevant to use, is seldom discussed or clarified (Finnveden, 1997; Lindahl, Robèrt, Ny, & Broman, 2014; Robèrt *et al.*, 2002).

1.2 Guiding product development

Important demands on a business organisation arise when the goal is to integrate sustainability considerations into the product development process (Charter & Clark, 2008). Two key factors, identified by Charter

and Clark, are *acceptance of the goal* by managers on all levels, and employees' *motivation to learn and to change*. On the project level of product development, the literature similarly points towards the importance of the project team accepting a common goal and the working procedure, and the creation of motivation for the team members to participate in activities aimed at communication in order to facilitate learning (Decuyper, Dochy, & Van den Bossche, 2010; Mullen & Copper, 1994).

The focus for sustainability considerations of products has lately been on increasing the amount of raw material of renewable origin in products, and on measuring indicators like carbon dioxide emissions, i.e. less focus has been on the organisation. This has resulted in a lack of understanding of how change can be created in a company in practice, despite that this understanding is required to successfully integrate a shared vision or to affect a changed behaviour, such as greater sustainability thinking in a company (Book *et al.*, 2006; Todnem By, 2005). Moreover, understanding organisational change is becoming even more important as the significance of inter-organisational projects is on the rise.

1.3 Aim of the thesis

The aim of the research presented in this doctoral thesis is to better understand both enablers and obstacles in developing sustainable products, and to provide a basis for actionable work for the development of more sustainable products.

The objectives of this thesis are to:

1. Investigate how product sustainability assessment can be performed in early product development to become useful for the development team
2. Investigate how a management system can influence direction, and how the work practices in product development can be utilised to guide towards more sustainable products

Based on these objectives, detailed questions that focus the work behind this research have been defined, see Section 1.5.

1.4 Delimitations

In this research, the focus has been physical products, i.e. artefacts, even though services might be mentioned as solutions or part-solutions for making products more sustainable.

The focus is on the early development stage, minimal attention is on needs related to the other stages in product development, such as scale-up, optimisation and improvement. Market-economic factors within product development are not addressed in this thesis.

1.5 Research questions

Before approaching how product sustainability assessment can be performed, the way in which product sustainability is assessed today needs to be studied.

> *Research question 1*: Which parameters are presently used in product sustainability assessments? (**Paper I**)

To understand the possibilities and limitations of a tool for the assessment of product sustainability in early product development, the tool must be explored and evaluated.

> *Research question 2*: How can environment assessment tools be utilised to guide in the early stage of product development processes? (**Papers I, II, III, V** and **VI**)

Many different skills are needed to develop more sustainable products, and the requirements on work practices for achieving a successful outcome are beneficial to understand for the purpose of guiding in early product development.

> *Research question 3*: What are the enablers and obstacles in work practices in the development of more sustainable products? (**Papers IV, V** and **VI**)

To understand how a company's management systems can influence their sustainability work in product development, the way in which the company integrates sustainability into their product development can be studied and compared.

> *Research question 4*: How can sustainability considerations be integrated into the early stages of product development? (**Papers IV, V** and **VI**)

1.6 Outline of research work and thesis

The thesis presents six theoretical and empirical research papers. The scopes of the six appended papers and their relation to each other and this thesis are illustrated in Figure 1.

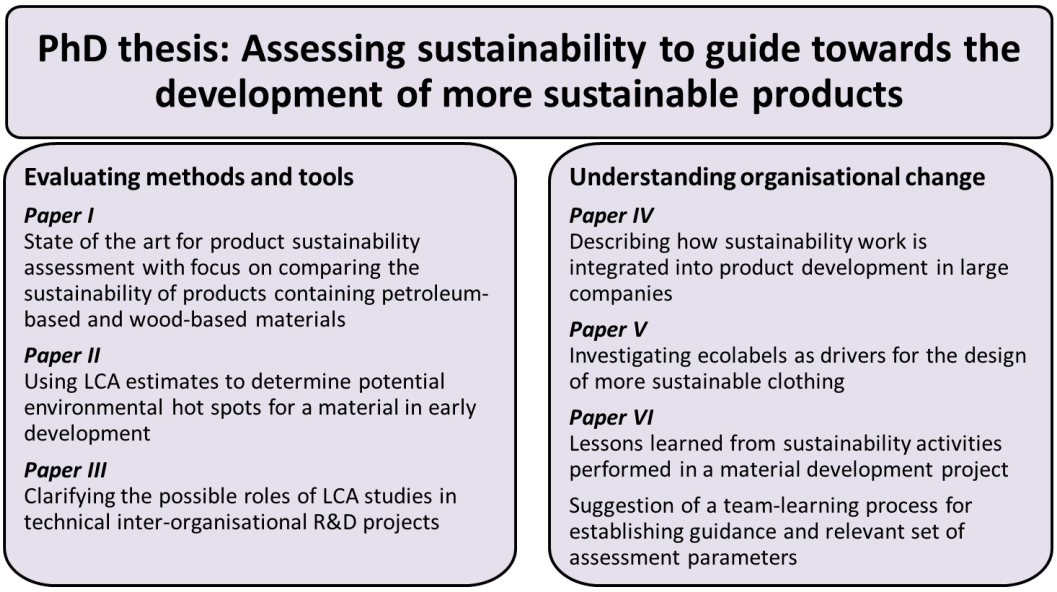

Figure 1. *This doctoral thesis discusses assessing sustainability and guiding development towards more sustainable products. The research is presented in six papers on evaluating methods and tools, and on understanding organisational change.*

The aim of the attached papers is to provide knowledge on how to assess and guide development towards more sustainable products. The point of departure for the papers is either in evaluating methods and tools, or understanding organisational change. The research is discussed in a broad theoretical context in the subsequent chapters, and is presented separately in the appended papers.

Papers I to **III** mainly cover the evaluation of methods, and **Papers IV** to **VI** focus on understanding organisational change, however, all the papers, to some extent, cover both subjects. A summary of each paper and each paper's contribution to the thesis are provided in Chapter 4.

2. DEVELOPMENT OF MORE SUSTAINABLE PRODUCTS: LITERATURE BACKGROUND

This chapter provides an overview and discussion of the literature selected as relevant for the thesis. First, sustainable development is defined to clarify what this means for developing towards more sustainable products, as well as the importance of sustainability awareness in the early product development stage. Second, considerations when integrating sustainability into early-stage product development are presented. Then, the concepts actionable knowledge and action competence are introduced. The importance of team learning in guiding product development is discussed. Thereafter, the influence of leadership on organisational behaviour is described. Finally, the components and functions of a management system are outlined.

2.1 Sustainable development and the early product development stage

There is general agreement in the world on the need to move towards a more sustainable society. However, how this is to be done and which goals should be examined in detail are viewed differently (Kates, Parris, & Leiserowitz, 2005). Furthermore, depending on the situation, different sustainability aspects may be more or less urgent, or important, to consider (IPCC, 2014a). The most common definition of sustainable development is the one from the World Commission on Environment and Development, often called the Brundtland definition:

> *Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their needs. (WCED, 1987 p.16)*

Sustainable development is an overarching concept, and the Brundtland definition of sustainable development contains two points that could be a reason for its widespread use. One is that the definition, by referring to the *needs of future generations,* appeals to emotion, which makes individuals think more long-term. Second, the phrase *humanity has the ability* enhances a sense of possibility. Thus, these two points together spur individuals to take action and to participate in activities towards improving sustainability. Actions for sustainable development have been stated to

succeed if they are done in time, e.g. by precursor Meadows *et al.* (1972) later by Stern *et al.* (2006) and recently by IPCC (2013, 2014a, 2014b).

Since the establishment of the Brundtland sustainable development definition and the Rio conference (UN, 1992), there has been an ongoing discussion both on how to interpret and how to operationalise the concept of sustainable development. A recent effort, presented by Griggs and co-workers, interprets sustainable development in relation to the planetary boundaries introduced by Rockström *et al.* (2009): (Rockström *et al.*, 2009)

> *Development that meets the needs of the present while safeguarding Earth's life-support system, on which the welfare of current and future generations depends. (Griggs et al., 2013)*

A comparatively early effort to operationalise sustainable development was the four sustainability principles proposed by John Holmberg and Karl-Henrik Robèrt around 1990 (Holmberg, 1998).

In order for a society to be sustainable, nature's functions and diversity must not be systematically:

1) subjected to increasing concentrations of substances extracted from Earth's crust;
2) subjected to increasing concentrations of substances produced by society;
3) impoverished by over-harvesting or other forms of ecosystem manipulation, and
4) resources must be used fairly and efficiently in order to meet basic human needs worldwide.

These principles have been worded differently over the years, but nevertheless have the same basic meaning. These principles are intended to give guidance regarding the desired direction of change, and they have been used as a starting point for envisioning the characteristics of a future sustainable society, which has been contrasted with existing corporate reality, in order to formulate strategies for sustainable development (Holmberg & Robèrt, 2000). These strategies also include more focused efforts on understanding the key elements for implementing a strategic sustainability perspective in the early phases of the product innovation process (Hallstedt, Thompson, & Lindahl, 2013).

When operationalising sustainability on the company level, simple tools like listing *unsustainable* versus *sustainable* materials, products and activities are often requested (Mulder, 2006). There are two main shortcomings of such a list. One is that sustainability requirements are

valued qualitatively as *yes* or *no*, and thereby, cannot offer solutions for improvements. The other is that the relationship between different sustainability requirements is undetermined (Kishita *et al.*, 2010). The advice provided by such lists also depends on the underlying description of sustainability. Thus, what sustainable development means in practice, for a specific situation, cannot be described only in generic terms (Kates *et al.*, 2005; Mitchell, May, & McDonald, 1995). There are also more sophisticated models that, instead of simple lists, organise the sustainability questions into subject areas, such as the LiDS wheel (van Hemel, 1998).

According to Baumann et al. (2002, p. 418) it is generally recognized that the conceptual stage is the most influential one with regard to a product's environmental performance, although no empirical references support this. Thus, strategies and assessments for reducing the negative sustainability impacts of a company and their products should preferably be utilised at the conceptual product development stage. The reasons for this are that many of the sustainability burdens of a product are determined through choices that are made at the early product development stage, and at this stage, the cost of change is comparatively low (Bhamra & Lofthouse, 2007; Ramani *et al.*, 2010; Ritzén & Beskow, 2001).

Product development is initiated by an idea, demand or challenge, such as sustainability, and, if successful, ends with a product on the market. An illustration of different development stages that can be discerned for products is presented in Table 1. The table shows how the wording *early product development stage* is used in this thesis. The description in Table 1 builds on Wrisberg *et al. (2002),* who describe levels of environmental improvement based on the time horizon and the degrees of freedom of the criteria technical, social and institutional innovation.

Table 1. *The early product development stage as used in this thesis in relation to the other stages of product development, based on Wrisberg et al. (2002) and further discussed in Clancy (2012)*

Product development stage	Early development	Development	Demonstration	Production	Upgrade
Situation	A first idea of a new material or product concept exists	Product concept exists but details are not set	Material or product is available in small quantities	Material or product is available on the market, the production process is known	Material or product needs to be renewed
Task	To develop idea and concept	To develop towards defined properties	To scale-up production processes	To optimize production processes	To improve material or product for example by optimisation or replacement of part or process
Time horizon	Several decades / long-term	Years to decade /medium-term	Months to years / short-term	Months to years / short-term	Months to years / short-term

In the early stages of product development (the left-hand side of Table 1), the resources or materials to be used, the amount needed, where and how the materials and products will be produced or the potential production volume are all unknown factors. The degree of uncertainty in terms of product system and the size of the market is high. This uncertainty provides a challenge to sustainability assessment, since many of the details needed for a thorough sustainability evaluation are not available. At the same time, there is a major opportunity to influence the process towards a more sustainable final product before all these potentially important choices have been made. On the right-hand side of the table, more is known about the product system and there are fewer degrees of freedom for product development. On the left-hand side, there is a need for more long-term and future-oriented guidance towards a vision of sustainability.

A product development team in the early product development stage consists of members with various skills. The specific skills needed depend on the situation and the task of the project. In this thesis, the permanent product development team members (for at least one stage in Table 1) are referred to as developers. The role of the developers in industry is shifting from solving simple problems to solving complex problems, and from working independently with a single-discipline focus to working collaboratively with cross-functional teams (Lockwood, 2009).

Developers frequently interact with industrial designers, increasingly even during early-stage product development (Jahnke, 2013). Sometimes designers are part of permanent product development teams, and other times they come in as external consultants. Perks, Cooper & Jones (2005) have identified three different roles that designers can play in new product development. In the first role, *design functional*, the designer concentrates purely on the traditional designer task of creating a product's visual appearance. In the second role, *design functional integration*, the designer is part of a multifunctional team in which the designer typically focuses on communication and interfacing activities. The third role, *design functional integration leadership*, envisions the designer as a process leader. A process leader drives and supports actions, and is present throughout the entire product development process and across functional activities. Perks, Cooper & Jones (2005) have identified the first role as the most common in incremental product development which introduces products quickly and frequently, e.g. in clothing design, while the third role is mainly used in radical product development. In this thesis, designer refers to the first role if nothing else is stated. Thus, in this thesis, a designer can be a temporary member of the product development team, but not a developer.

2.2 Considerations when integrating sustainability into early product development

The practical philosopher Christian Munthe lists three questions that should be answered before performing any assessment in order to ensure transparency and to avoid being influenced by expected or wanted results (Munthe, 1997):

- What should be included in the issue?
- How should any trade-offs be made?
- How should uncertainty be handled?

Since the same type of questions have also been highlighted for comparing products (Clancy, 2012; Steen, 2006), they are most likely useful as a basis for any product assessment. What is relevant to include in the sustainability issue for a product under development depends on what is to be achieved, such as improvement level and time horizon. The way in which trade-offs between concerns and the uncertainty of necessary information should be handled depends on the context throughout the entire product life cycle.

Incremental or radical change

As discussed by Charter and Chick (1997), environmental problems caused by industry have traditionally been addressed by end-of-pipe or repair strategies that minimize environmental impacts. In the long run, this often turns out to be costly and inefficient because it does not provide solutions to the problem from a systems perspective (Waage, 2007).

Currently, most environmental improvements are taken in small steps, so called incremental improvements, incremental innovations or refine of existing product (Wrisberg *et al.*, 2002). One reason for this is that radical improvements, or rethink, often go beyond the scope of individual companies, and demands change in contact with other organisations or infrastructures.

A number of concepts and tools, like Ecodesign, Cleaner Production and Life Cycle Assessment (LCA) have been developed to make it possible to integrate environmental or sustainability aspects into different stages of product development (Karlsson & Luttropp, 2006). These tools focus primarily on the optimisation of a current product system, e.g. on replacing parts or processes responsible for major environmental impacts based on the industrial processes currently in use. The optimisation of current product systems normally results only in marginal improvements of the current situation, and cannot fully take advantage of the truly innovative ideas that are based on completely different solutions (Charter & Chick, 1997; Dyllick & Hockerts, 2002; Wrisberg *et al.*, 2002). Since a more sustainable future society might put very different demands on products compared to the strictest environmental requirements of today, sustainable product development must be future-oriented, i.e., it must be based on a vision of long-term sustainability and on an understanding of what challenges this poses to the product system that is being developed. This difference in focus, on future-orientation instead of optimisation, has been discussed by Van Weenen (1997) in relation to sustainable product development. He argues that future-orientation requires that a project team considers both a broad systems perspective and a life cycle perspective.

Companies, to a greater extent than today, need to define their visions and strategies with a long-term perspective in mind *and* communicate the strategies to their product developers in order to manoeuvre company activities through issues like anticipated resource and policy restrictions (Baumann *et al.*, 2002). It follows that companies need to make trade-offs in their product development according to their specific circumstances, like company size, available cooperation and type of product. One decision a company needs to take is whether or not *repair*, a so called end-

of-pipe solution, and *refine*, i.e. stepwise improvements in products and processes, are sufficient for achieving their goal. Or whether or not significant improvements like *redesign,* by incorporating sustainability factors, or even *rethink,* by emphasising creative problem-solving and opportunity-seeking, is also necessary to remain in operation in the long term (Charter & Chick, 1997). Similarly, Wrisberg *et al.* (2002) discuss four levels of improvements in terms of Incremental improvements; Redesign of existing concepts; Alternative fulfilment of functionality and System innovation (Wrisberg *et al.*, 2002). Nidumolu *et al.* takes this all the way by claiming that "*Sustainability = Innovation*" (Nidumolu, Prahalad, & Rangaswami, 2009). The reasoning is that challenges such as climate change, resource limitations and population growth mean that, in order to survive, companies will have to change the way they do business by developing innovative and sustainable solutions.

Both incremental and radical product changes are necessary for companies and products to become more sustainable. For this reason, companies need to choose the type of change through which they are able to accomplish meaningful benefits for society that are valuable for business at the same time. Such a *shared value* needs to be identified, because a short-term gain for one part only, i.e. for society only or for the company only, would risk undermining the long-term prosperity for both (Porter & Kramer, 2006; Porter & Kramer, 2011). Nidumolu *et al.* (2009) have presented five successive development steps for companies as regards sustainability: Viewing compliance as opportunity, Making the value chain sustainable, Designing sustainable products and services, Developing new business models and Creating next-practice platforms. Each of these stages has different challenges, and skills to manage these challenges must be developed. For example, the first stage, Viewing compliance as opportunity, would benefit from complying with the most stringent rules, and doing so before they are enforced, rather than adhering to the lowest standards for as long as possible. Most companies go through these five stages on their way to becoming sustainable (Nidumolu *et al.*, 2009). The first three steps could be managed by incremental improvements. While, The fourth step, Developing a new business model would, most likely result in a radical change in a product or service, and may typically take place at the early stage of development (Chesbrough & Rosenbloom, 2002).

In several areas where radical changes are required, an individual company cannot address the task on its own, but must collaborate with others, e.g. other companies, research institutes, universities, legislators and consumers. For example, electric cars have been available for quite some time, but since a charging infrastructure has not yet been developed,

they have not become the first choice of consumers (Dickerman & Harrison, 2010; Eberhard & Tarpenning, 2006). Organising such a well-functioning electric car system is what Nidumolu *et al.* (2009) call a next-practice platform, i.e. a platform on which other companies can develop innovations as well.

Long-term considerations

The Brundtland definition (WCED, 1987) of sustainable development is based on the principle of intergenerational equity, and thereby, requests that the ability of future generations to meet their needs is not jeopardised. For product development, this implies that companies need to have a long-term strategy to avoid moving in an unwanted direction, and to avoid the lock-in effects of unsustainable systems created by investing in development and assets that they ultimately need to shift away from (Hoffrén & Apajalahti, 2009; Westley *et al.*, 2011; Williander, 2006, 2014).

An important feature of any product, therefore, is that it has the potential to fit into a sustainable society, or at least be a bridging solution that can assist in a move in the desired direction (Broman, Holmberg, & Robèrt, 2000). A long-term perspective is needed that includes not only today's major challenges, but also potential upcoming future challenges. Such challenges can be estimated by identifying unsustainable trends in, for example, consumption and the availability of resources, and by attempting to anticipate critical incidents that may alter the situation in the future (Clancy, Fröling, & Svanström, 2010; Edgar & Alänge, 2014; IPCC, 2014a).

Several approaches to introducing long-term considerations are based on applying the four principles for sustainability (Holmberg, 1998). For example, a four steps backcasting procedure for strategic planning towards sustainability (Holmberg & Robèrt, 2000). These are: 1) Defining the criteria for sustainability; 2) Describing the current situation in relation to the criteria for sustainability; 3) Envisaging and discussing the future, and 4) Finding strategies for sustainability.

The aim of one such approach is to develop and test the robustness of a business idea (Lundqvist, Alänge, & Holmberg, 2006). However, the use of this approach in a product development team has not been described. Another approach takes this step further, and develops guiding questions to promote a broad systems perspective in product development (Byggeth, Broman, & Robèrt, 2007). As a complement to the guiding questions, and to provide an overview of major sustainability challenges and opportunities early on for company management and the product

development team, templates for sustainable product development have been proposed (Ny, Hallstedt, Robért, & Broman, 2008).

It can be argued that the above approaches will always require a facilitator to develop and/or choose the relevant guiding questions for sustainability since the backcasting is not known or understood by the product development team members themselves. Consequently, the desired understanding product developers need, to be able to continue making informed decisions that lead to more sustainable products, cannot be attained unless additional measures that focus on team learning are introduced (Clancy, 2012).

Life-cycle thinking

Products have impacts on sustainability not only during production in the factory, but from raw material extraction, through material production and product manufacturing, to use and waste management. To be able to improve sustainability and not only shift the burden from one life cycle stage to another, products should be considered from a 'life cycle perspective' or 'cradle to cradle' perspective (McDonough & Braungart, 2002; Rebitzer *et al.*, 2004). Thus, a newly developed material will not only affect resource acquisition and material production, but also the manufacture of the products that use the material and potentially even the use of those products and their waste management options. This means that a newly developed material should be analysed with life cycle tools. LCA (Baumann & Tillman, 2004; ISO 14040, 2006; ISO 14041, 1998; ISO 14042, 2000; ISO 14043, 2000; ISO 14044, 2006), Cradle to Cradle (Braungart, McDonough, & Bollinger, 2007) and the LiDS wheel (van Hemel, 1998) are a few examples of tools that utilise life cycle thinking.

The entire life cycle of a product needs to be envisaged in order to allow for relevant descriptions of sustainability issues for the product (Seuring & Müller, 2008). A description of a 'sustainable product' must be made in relation to the challenges that become visible when the entire product system is examined in relation to its surrounding world, which, to complicate this further, also changes over time. For this reason, an appropriate time perspective is required. Consequently, it is unwise to talk about 'sustainable materials' since the sustainability of any material will depend on the full life cycle of the products in which it may be used. Thus, any assessment of materials must put them in a context.

Selecting relevant sustainability parameters

Assessments are used to compare different product systems, mainly in the development, demonstration and production stages of product

development, as described in Table 1. Assessments reported in the literature, often use lists of predetermined parameters without critical reflection on their relevance in light of a specific situation (Bossel, 2001; Niemeijer & de Groot, 2008). How and why certain sets of parameters are selected is normally not described; they are often referred to as the 'selected' or 'chosen' parameters, indicators or impact categories, without any explanation of how or why the parameters are relevant.

One example of this is labelling systems that guide in material choices. An ecolabel is not a guarantee for a more environmentally sustainable material or product than a material or product without a label, since the labelling systems often only consider a few requirements, and do not have a broad system perspective (Rex & Baumann, 2007). Furthermore, the requirements of the labels are mainly based on current issues, and might not point in a direction that is sustainable in the long term (Bratt, Hallstedt, Robèrt, Broman, & Oldmark, 2011). It has even been argued that present eco-labelling criteria might create barriers to sustainable innovation (Bratt *et al.*, 2011).

How to prepare an organisation for working with sustainable development was explored by the International Institute for Sustainable Development in 1996. Their review of practical efforts for measuring, monitoring and assessing progress towards sustainability resulted in the ten so-called Bellagio Principles (Hardi & Zdan, 1997). These ten principles emphasise necessary elements for successful sustainable innovation: a guiding vision and goals, a holistic perspective, essential elements, adequate scope, practical focus, openness, effective communication, broad participation, ongoing assessment and institutional capacity. Another document, the International Standard for *Integrating environmental aspects into product design and development* also sets guidelines for issues to consider in a product development process, and points out that product development is an iterative process in which information exchange, dialogue and collaboration are important features (ISO 14062, 2002). Neither of these two documents, however, provides any guidance to how to establish relevant product sustainability assessment parameters, in practice, in product development.

There is a need, in product development, to reflect upon the impact of a product or activity on sustainability from a long-term, broad system and life cycle perspective to be able to develop more sustainable products. Several authors point out that integrating such sustainability thinking into product development is not easy and not a matter of developing more methods and tools or collecting more data. They mean that this is an organisational problem (Baumann *et al.*, 2002; BSI, 2004; CALCAS, 2008)

that involves the *acceptance of the goal* by managers on all levels, and includes employees' *motivation to learn and to change* (Boks, 2006; Charter & Clark, 2008).

2.3 Action competence and sustainable development

Finding solutions to the great challenges that face humanity due to resource limitations and population growth requires societal and individual changes (Gore, 2006; Meadows, Meadows, Randers, & Behrens III, 1972; WCED, 1987). A change in perspective is needed. Such change in perspective requires envisioning alternative paths of development. Many different skills, as well as the willingness to learn, are necessary to foresee the impact of such paths both locally and globally (IPCC, 2014a, 2014b; Meadows, Meadows, & Randers, 2004).

The concept action competence includes the willingness and capability to learn, as well as the courage and skill to act. Action competence, was originally introduced by Jensen and Schnack (1997) within the field of environmental education and focuses on the individual level. They argue that action competence should have a central role in all environmental education, since knowledge about existing environmental problems has been proven insufficient for making people act on environmental concerns. This approach is supported by others who have found that environmental and quality work in organisations has a tendency to get stuck in theory (Book *et al.*, 2006).

Jensen and Schnack (1997) describe action competence as the ability to act, in which the action is aimed at solving a problem, and experience is the result of an action performed. For example, collecting the sustainability data on a product is an activity that increases knowledge. Action would be an activity that solves the problem that creates the negative sustainability impact observed. Action competence would be the ability to select an appropriate action and the willingness to undertake this action e.g. initiating collection of data and understanding that it needs to be done. The systematic learning process of action competence can be discussed in terms of the plan-do-study-act circle for iterative and continuous learning (Moen & Norman, 2006). Competence is associated with being able and willing to be a qualified participant. Consequently, action competence involves several aspects, whereas 'competence' itself is traditionally related to the concepts in the upper left section above the diagonal line in Figure 2 (adapted from Breiting *et al.*, 2009).

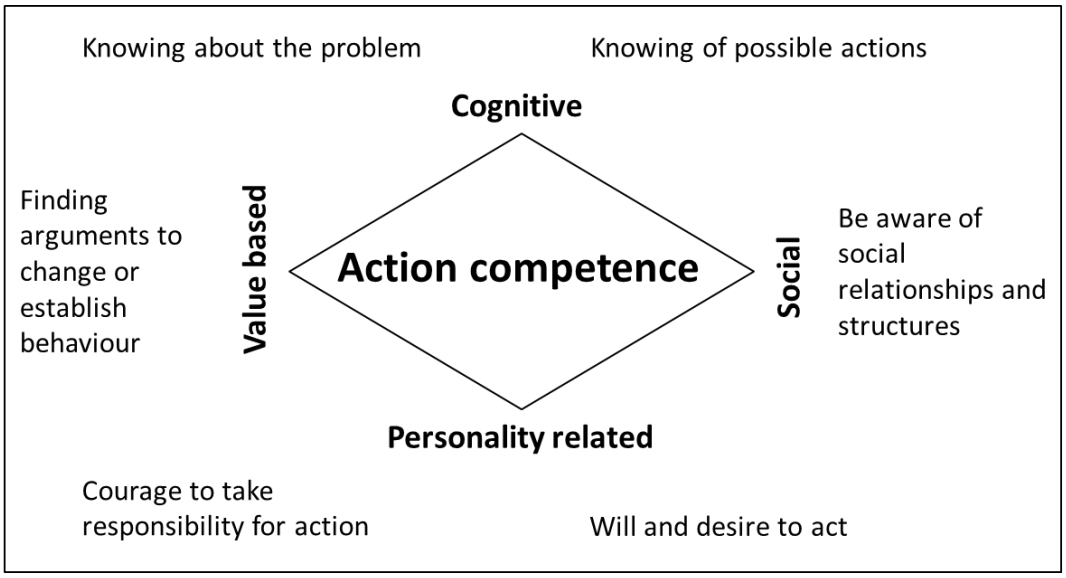

***Figure 2**. Major aspects of action competence (adapted from Breiting, Hedegaard, Mogensen, Nielsen, & Schnack, 2009)*

The elements of action competence, as illustrated in Figure 2, can be divided into four categories: Cognitive, Social, Personality related and Value based. Cognitive means having knowledge about a problem and having knowledge of possible actions. Social means being aware of how social networks function and how they can be structured. Personality related means having the courage to take responsibility for an action, and having the will and desire to act. Personality related naturally depends on the individual, but is also dependent on the surrounding organisation, which will be further discussed in Sections 2.4 and 2.5, e.g. how an organisation treats failure. Value based signifies the ability to change perspectives and find the drivers for the perspectives. Action competence is the sum of all these elements.

Almers, defines action competence for sustainable development as:

> *the willingness and capability to act for changes in individual life style, as well as for structural changes of society, in a way that includes responsibility for present and future generations, globally (Almers, 2009)*

This definition includes individual and societal actor perspectives, but totally lacks the actor perspective of businesses (Petala, Wever, Dutilh, & Brezet, 2010; Pujari, 2006). Businesses might be unsure of what their responsibility or role in developing more sustainable products involves (Shrivastava, 1995), which could be the reason that businesses traditionally focus on 'in-house' environmental issues (Nilsson-Lindén,

Baumann, & Diedrich, 2013). Yet, to develop more sustainable products requires various skills and collaboration between individuals, both internally and externally, and thus, cannot be solved by one individual or within a single business.

Actionable knowledge (Argyris, 1996) is a concept connected to action competence. Actionable knowledge is the knowledge that informs human beings of how to create and integrate different skills to effectively implement the intentions behind them. However, Agryris claims that knowledge often indicates conflicting actions, is contradictory to stated objectives, or in other ways is presented in a manner which prevents the knowledge being taken into account in decision making.

2.4 Team learning for guiding in product development

In order for a product development team to be able to make informed decisions, it needs to be continuously informed about important sustainability considerations and the potential effects of choices made. The importance of team learning in guiding product development has been pointed out by several authors (Edmondson & Nembhard, 2009; Hardi & Zdan, 1997; ISO/TR 14062, 2002). In this thesis, effective team learning refers to the process of working collectively to achieve common objectives in a group by acquiring, sharing and combining knowledge through experience with one another (Decuyper *et al.*, 2010).

The need for a team-learning approach has been highlighted in findings from field studies at two large enterprises in the Swedish forest product industry, both with more than ten years of experience with LCA work (Rex & Baumann, 2006). The authors concluded that the translation of life cycle thinking into practical everyday work in each team is necessary for using LCA to deliberately guide the development process. Many of the employees in the field studies, including those who understood the life cycle concept, failed to see any link between the life-cycle-thinking ambitions of the company and their own everyday work.

Charter and Clark (2008), emphasized the need to identify an organisation's level of awareness and understanding of sustainability issues, since these will determine the type of approaches, the training, and the communication that are needed. In a project involving cooperation between several different types of organisations and cultures, this identification and training will most likely require more time than when performed within a single company. For this reason, the project on Sustainability Integrated Guidelines for Management developed the

SIGMA Guidelines to provide practical advice to organisations in their efforts to contribute to sustainable development (BSI, 2004). The guidelines focus on how to cooperate across knowledge areas and organisational boundaries in order to utilise knowledge that exists in the different parts of the organisations. However, if team members are not committed to participating, such efforts most will most likely fail (Mullen & Copper, 1994). One identified reason for poor commitment is that conventional project setups often tend to limit learning and inhibit a long-term perspective by focusing on predefined outcomes and working on delivering results for those expected outputs, instead of reflecting on outcomes and stimulating learning (Bell & Morse, 2004, 2007). This creates a gap between the ambition to develop more sustainable products and the delivery practice of conventional projects. Bell and Morse (2007) have described a conventional project as *"defined activities carried out by defined people with a defined end point in mind at a defined cost and over a defined period of time"*.

Beer and Eisenstat (Beer & Eisenstat, 2000) have found that there are often hidden communication barriers to overcome when implementing strategies and achieving learning and change within an organisation. A lack of shared understanding of project goals and of terms used in the project, such as renewable resource, waste and product sustainability, generally make projects inefficient and create unnecessary tension and frustration (Decuyper *et al.*, 2010). Open, vertical communication is important for overcoming such barriers (Beer and Eisenstat, 2000). All levels in the organisation need to be engaged in an open dialogue about the organisation's vision in order to acquire a shared understanding.

2.5 Leadership and organisational behaviour

Management processes aim to bring order and consistency, while leadership has a different focus, namely to create movement and change, which has been expressed as follows:

> *.. the difference between a leader and a manager rests on status quo: Managers are willing to live with it, and leaders are not. (Bennis, 1997)*

Both managers and leaders are needed for an organisation to develop, however, as managers and leaders are very different kind of roles, a single individual most likely does not have the qualities needed for being both manager and leader (Kotter, 1990; Zaleznik, 1977). In early-stage product

development, there is a need for leaders that can spur and facilitate change and development processes.

Leadership for change

Lewin, Lippit & White (1939) (Lewin, Lippitt, & White, 1939) have described three different leadership styles which they have called, authoritarian, democratic and laissez-faire. Generalising the description to a business setting, the authoritarian leader makes major decisions for the group completely alone, and shows the group what to do. The democratic leader encourages group discussions and group decisions in the choice of activities. The democratic leader cares for the employees by checking their achievements and commenting on them. The laissez-faire leader provides the employees complete freedom of action, designates work tasks, but refrains from participating in the work and/or checking up on employees, and does not evaluate and comment on their work, except when asked. The authoritarian leader was found to achieve more in quantity of work, the democratic one was found to achieve more in quality of work, and the laissez-faire leader was found to have poor group performance, both in quantity and quality. A fourth leadership style, non-leadership, was added to the description by Lippit & White (1943) (Lippitt & White, 1943). They have concluded that knowing that there is a non-leadership style actually makes employees more productive than a laissez-faire leader.

Other leadership styles, similar to the above, have been described. Goleman (2000), for example, refers to the six leadership styles: Coercive, Authoritative, Affiliative, Democratic, Pace-setting and Coaching (Goleman, 2000). The main leadership style for managing change would be Democratic or Goleman's Coaching style. However, Goleman emphasizes that leaders need many styles, and that a collection of the six leadership styles should be used in a flexible way to achieve a pleasant climate and an advantageous business performance. Goleman has also noted that most leaders cannot manage all the styles, therefore, they need to delegate tasks to others that can contribute with the leadership style required.

Leadership inevitably requires using power to influence the thoughts and actions of other people (Zaleznik, 1977). Leadership is necessary, but it does not always explain how a decision was reached. A decision depends on what information is available and how the information is handled. Knowing what prevents satisfactory information from being available when a decision is made, is useful to be able to influence a change or action.

Information basis for decision making

The manner in which decision makers in companies accept information can be seen as passing through three filters, according to the framework of Ansoff & McDonell (1990), see Figure 3.

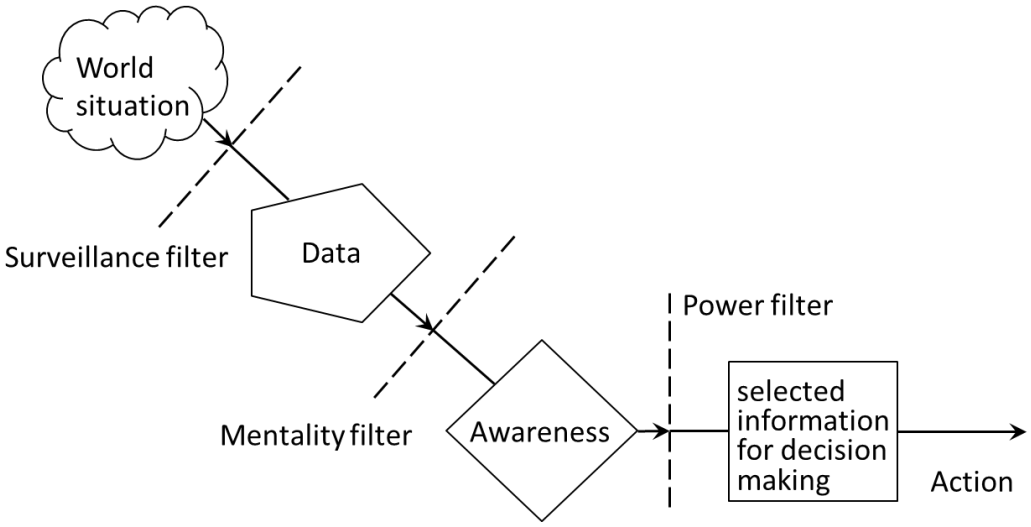

Figure 3. *Three filters which prevent decision makers' acceptance of novel signals of the world situation (Ansoff & McDonnell, 1990).*

First, there is the *surveillance filter*, which limits search activities to the area which the company is already familiar with and can handle. Second, there is the *mentality filter*, which indicates that decision makers in the company rapidly accept information that supports their previous assumptions, and they tend to avoid information that points in other directions. Finally, there is the *power filter*, which is essentially connected to decision makers' feelings that their positions are threatened by change. These feelings can be conscious or sub-conscious and thus, decision makers tend to filter out information that they perceive as potentially harmful. The primary reason for this behaviour is that decision makers develop their own success models based on historical experiences of what proved to be a successful action, which, especially in times of discontinuous change, can have a major blocking effect (Jarnehammar, 1995). Therefore, to assure company-wide acceptance of sustainability thinking, it is essential that top management be the leading practitioners of sustainability thinking.

It takes time to integrate a sustainability approach in a company, when a new way of thinking and prioritising is to influence work practices and behaviour on the individual level. Therefore, it can be useful to view the integration process as a learning process, both for the organisation and for its employees. This was the general observation from a project for strategic

planning towards sustainability at three multinational Swedish companies (Alänge, Holmberg, & Lundqvist, 2007). Consequently, it could take even longer time to integrate sustainability into an entire network or value chain, because of the increased complexity in coordinating various actors. However, the starting point is an understanding of how behaviour is influenced in each individual organisation. It is, thus, of importance to understand how an existing management system affects the way tasks are performed.

Understanding a management system's influence on behaviour in an organisation

A management system is the framework of processes and procedures used to ensure that an organisation can fulfil all tasks required to achieve its objectives (ISO Guide 72, 2001). The understanding of a management system's influence on work practices or behaviours in a company can be utilised to influence change and learning, e.g. when integrating sustainability thinking in a product development team. Management systems in different companies, and how they influence possibilities for change related to sustainability thinking, can be understood using the framework described in Figure 4 (adapted from Marmgren *et al.*, 2012).

The framework identifies three elements of guiding that influence the actual behaviour of individuals in an organisation: Spoken, Written and Tacit. Through these three elements, management influences behaviour and, thereby, work practices, e.g. the prioritization of resources, competence development, learning outcomes, risk management, business development plans and problem solving. The three elements influence each other and behaviour on all levels of an organisation. Behaviour, in turn, influences the elements. The level of influence is different in different organisations.

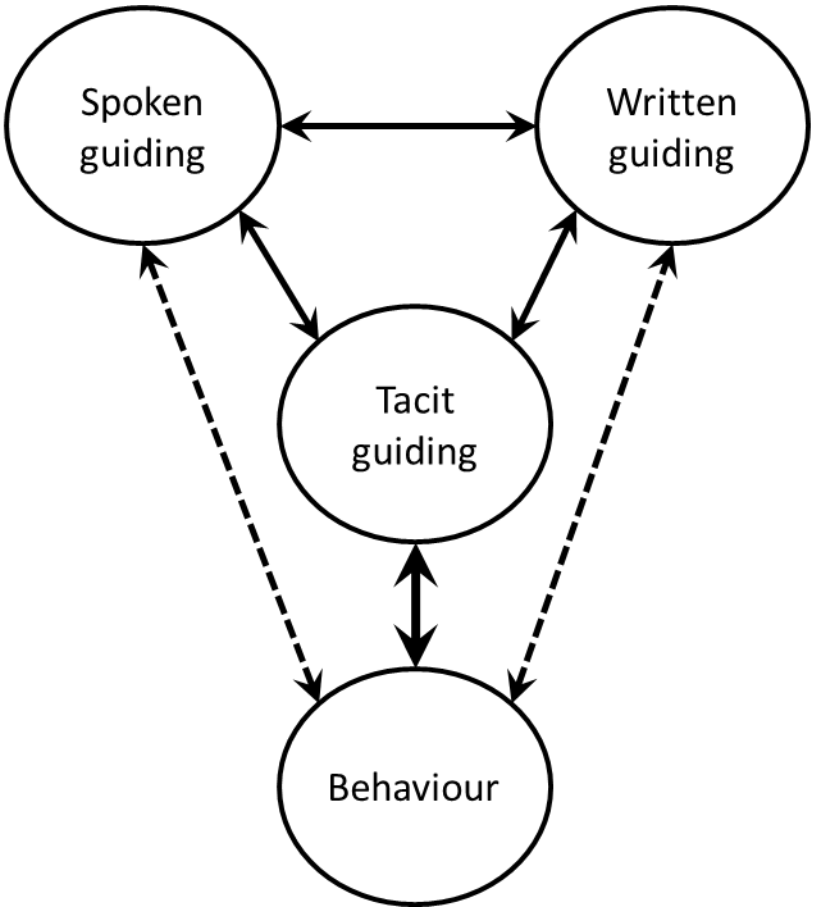

Figure 4. *A framework for understanding a management system's influence on behaviour in an organisation (adapted from Marmgren et al., 2012).*

Spoken guiding refers to oral communication, face to face, of company information such as strategies, values, practices, decisions made and news announcements in the organisation. What is spoken can be communicated in various settings, such as meetings, seminars and courses. Written guiding refers to written documents, such as strategies, standards, codes of conduct and specifications, as well as other document sources, such as pictures and films. The dotted lines in Figure 4 illustrate the commonly relatively weak relationship between what is spoken or written, and behaviour. Tacit guiding is an informal agreement on who does what and how to coordinate work. For instance, tacit guiding can include co-workers' understood idea of how things should be done in the corridors or on the shop floor (Argyris & Schön, 1996). Tacit guiding is created through interaction, and it has a major impact on individual behaviour patterns, shown as a thick solid line in Figure 4. The thin solid lines in Figure 4 indicate the relationship between different types of guiding, which can vary in strength. Therefore, the ambition of a change program is typically to reinforce the couplings between the three guiding elements, and as an

effect, influence the tacit guiding element which has a major impact on behaviour (Marmgren, Alänge, & Book, 2012; Weick, 1976).

Brief descriptions of two extreme management systems are given below, to show how the framework for understanding a management system can be interpreted.

In some organisations, the employees are highly influenced by written documentation. Employees refer to and are guided by documentation, such as standards, checklists, specifications and process procedures. Documentation tells them what to do and how to do it. Spoken guiding is followed as long as it confirms written guiding. Employees can find the written documents by themselves and a change can be influenced relatively quickly, as it is only a matter of changing the written documentation. This requires clearly written documentation, and fairly highly educated employees that search for, read and understand the documentation. Work-process-related issues not described in the written documentation will create a lot of uncertainty because the employees will not know how to handle these issues, and will not be helped by tacit guiding, because Tacit Guiding recommends them to seek information in the written documentation.

In contrast, some organisations are highly influenced by tacit guiding that tells the employees why, as well as what, to do. However, how to carry out a task is, to a high degree, decided by the individual employees or the teams themselves. Written documentation exists, in such a case, however it is not used on a daily basis, but rather to occasionally check decisions already made. New employees in such an organisation must listen and learn how things are done, which takes time, but when a new employee is integrated, their freedom to act is large. Tacit guiding is shaped by why and what, and is learned through practice, which means that uncertainties about how to act are limited, and development can proceed without much involvement from senior management.

3. METHODOLOGY

The research in this thesis is based on three empirical data sets. The first one was generated by participatory action research in a material research project. The second was generated by semi-structured interviews at two large consumer products company. And the third was generated by semi-structured interviews at three clothing companies. In this chapter, the research methods used are presented and, the backgrounds of the three empirical data sets are described, thereafter quality considerations and, finally, research ethical considerations are reflected upon.

3.1 Research approach

Different research approaches have been used in different parts of the work leading to the appended papers. An overview is given in Table 2.

Table 2. *Overview of the research approach in each paper*

Paper	Research approach
I ***Changing from petroleum to wood based materials: critical review of how product sustainability characteristics can be assessed and compared***	Literature-based study Gap analysis (Participatory action research)*
II ***Environmental challenges when developing renewable materials to replace non-renewable materials - guidance from LCA studies***	Utilisation of Life Cycle Assessment scenario studies in early product development(Participatory action research)*
III *Making the most of LCA in inter-organisational R&D projects*	Comparative analysis of LCA studies Knowledge sharing and reuse Triangulation of data sources and interpretation
IV ***Naturalizing sustainability in product development: A comparative analysis of two Large Companies***	Comparative case study of two large firms Re-analysis of earlier research data Semi-structured retrospective interviews Triangulation of data gathering and interpretation
V ***Ecolabels as drivers for clothing design***	Comparative study at a single point in time Content analysis Semi-structured interviews Triangulation of data interpretation
VI ***Insights from guiding material development towards more sustainable products***	Single case study over a period of time Participatory action research Systematic combining

* The **Papers I** and **II**, have *participatory action research* within parenthesis. This is to indicate that even though each of these studies could have been performed as standalone studies, giving equivalent results, they were actually performed as parts of a larger study, with the intention of influencing this larger study, and in close interaction with **Paper VI**.

Participatory action research means that the researcher takes part in a project and tries to change or improve something in an on-going project. In the material research project, the purpose was to provide input on opportunities and difficulties in guiding product development towards a more sustainable product. With the exception of the work experience mentioned in Section 3.2, pre-knowledge of the material research project was gained from i) a literature study including the companies' official documentations and official documents on the project content, ii) interviews with company personnel, such as sales and production representatives, and iii) field trips to the two companies and their operations, such as forest management, pulp production and end product manufacturing.

Participatory action research involves utilising a systematic cyclical method of planning, taking action, observing, evaluating (including self-evaluation) and critical reflection prior to planning the next cycle (Wadsworth, 1998). Participatory action research gives a narrow but deep view, and can give a greater understanding of the research area, and indicate certain results. The change part of participatory action research was, however, not fully achieved in the material research project, because the sustainability activities did not affect practice in the project (**Paper VI**). In Figure 5, this is illustrated as a lack of loop down into practice after the initial data collection. Learning was, thus, primarily obtained by the researcher, and, to a lesser extent, by the rest of the project team as illustrated in Figure 5.

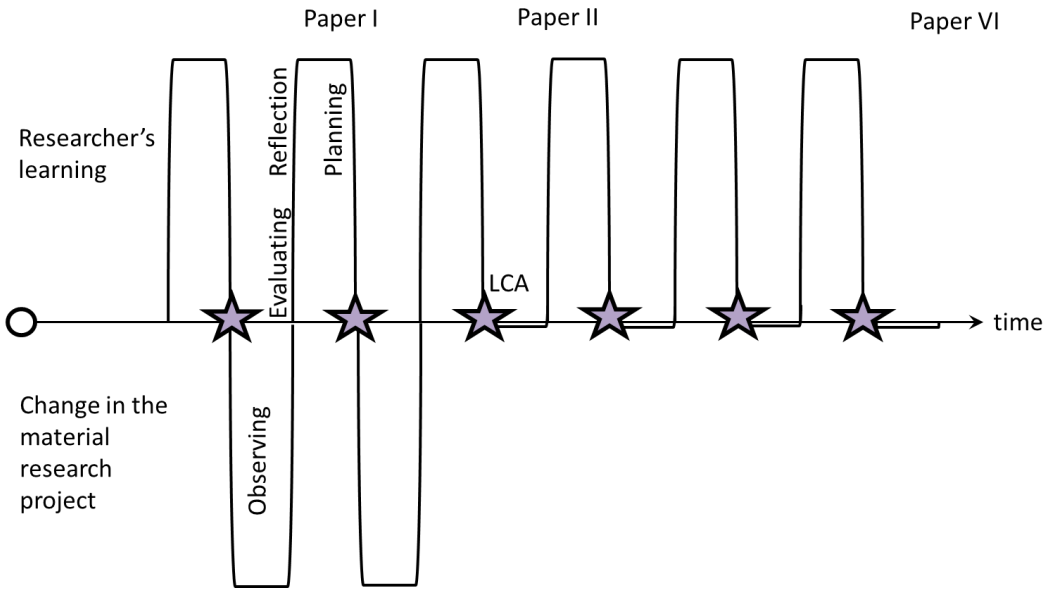

Figure 5. *Participatory action research in the material research project. An illustration of the researcher's learning, and the change within the material research project. Stars indicate sustainability activities as planned by the researcher and then observed, evaluated and reflected on before planning the next activity.*

Several sustainability activities, e.g. workshops, were carried out in the material research project, illustrated as stars in Figure 5, to accomplish the three different steps which were: 1) to define long-term goal and determining scope 2) to establish sets of product sustainability assessment parameters, and 3) to assess broad system product sustainability. However, because no change was introduced in the project, it was not possible to evaluate any results of suggestions, as shown in Figure 5 (Coghlan & Brannick, 2009). The learning was, however, used by several project team members in other projects outside the scope of this particular project.

The activities were all conducted with the intention of resulting in a product that would perform better than a reference product. Since all of the exercises were performed before the final assessment framework, presented in **Paper VI**, had been finalized, they all aimed at both providing input to the forming of the assessment framework, and at providing guidance to the team on how to extend the sustainability performance of the end product. The research approach in **Paper VI** can be seen as an iterative process in which empirical findings inform theory and vice versa, while the analytical framework develops along with the case. Dubois and Gadde (2002) call this abductive approach **systematic combining** (Dubois & Gadde, 2002).

The **literature-based study** (**Paper I**) had two main research questions: 1) What sustainability aspects have been studied or considered as important for a product?; 2) What methods / tools exist for sustainability assessment of products, especially in the early phases of product development? Examples of keyphrases are "sustainability AND parameter AND product", "sustainable product development", "Sustainability assessment method" and sustainability assessment model". Automatic alerts were set on the mentioned search strings and certain authors to obtain relevant updates continuously. The main database used was Scopus and the main search engine was Google Scholar. A **gap analysis** can be used to determine the needed capabilities that do not yet exist by seeking and comparing the answers to the questions "what can we do?" and "what do we want to do?". Gap analysis was used to demonstrate limitations in the available assessment methods for the needs in the material research project.

Life Cycle Assessment (LCA) can be used to analyse environmental impacts from the life cycle of products, i.e. from raw material extraction via material production and product manufacturing to use and waste management (Baumann & Tillman, 2004; Finnveden *et al.*, 2009; Pennington *et al.*, 2004; Rebitzer *et al.*, 2004). LCA is a standardised method for the environmental assessment of products, and is included in the ISO 14040 series. LCA is often used to compare products with the same function, but can also be used to identify 'hot spots', i.e. parts of the life cycle of a product that are critical to the total environmental impact of the product. In the early product development stage, as in the material research project, full LCA cannot be applied because material production data is not yet available. LCA can, however, be applied in other ways in early product development (Baumann, 2014). The LCA study in the material research project (**Paper II**) was based on data for a reference product in order to visualise the environmental window of opportunity and challenges for the product under development.

An empirical study is a way of gaining knowledge by means of direct and/or indirect observation or experience. Empirical data can be collected through measurement, observation, interviews and surveys. In **Paper III**, the six authors' experiences and observations of different empirical studies are **shared and reused** in the study reported in the paper.

The interviews in **Papers IV** and **V** were conducted as **semi-structured interviews** in which the interviewer/s had set up a general structure in advance by selecting the subject and preparing the main questions to be asked. The sequence questions that are asked, whether and how particular areas might be followed up and developed with different interviewees is

left to the interviewer to work out in response to the dialogue. Semi-structured interviewing is a very flexible technique and is suitable for mini-studies and case studies (Drever, 2003). The three first interviews for **Paper V** were carried out by the author of the thesis. Notes from the interviews were transcribed directly afterwards. The fourth interview was performed together with a co-author to limit subjective interpretations, and this interview was also recorded to open up opportunity to go back and check data or citations. In **Paper IV**, all three authors of the paper participated during the five retrospective interviews and all the interviews were recorded.

3.2 The author's background knowledge and possible bias

The author of this thesis had worked as an environmental specialist within product development and other areas for several years before returning to the university environment and PhD studies. This means that the author had prior experience of business, product development and environmental work, which can be both positive and negative for a PhD research project. One advantage is that such experience enables the author to relate to how product development is organised in companies, and how environmental tools can be applied in such practice. This prior knowledge may, however, also prove to be a bias that prevents the author from identifying and understanding a matter or situation (Bryman & Bell, 2011).

3.3 Three empirical data bases

Participatory action research in a material research project

The first years of the PhD project were carried out in the context of a material research project. The research project was managed in the form of cooperation between a multi-national end-product manufacturer/forest owner, a Swedish pulp producer/forest owner, and Chalmers University of Technology. The research project was funded by Vinnova (Sweden's innovation agency) and the two companies. The research had a specific focus on developing new wood-based materials with the potential to replace non-renewable materials in a product, while ensuring that the new product would also be more sustainable than a reference product (Roberts, 2009; VINNOVA, 2008; WooDi, 2010). Different sub projects focused on areas such as creating assemblies of fibres with tailored properties, the characterisation of fibre composition, and designing the production process. The author's research was part of the sub project that focused on assessing the sustainability of the life-cycle of the new products, with the

intention to guide the material research process towards a more sustainable final product. The material research team consisted of graduate students, their supervisors and senior researchers from the two companies. **Papers I, II** and **VI** are directly based on work within this project.

Continued research, after the material research project was finalized, was initiated, designed and planned mainly by the author of this thesis. The research was designed to facilitate understanding issues that emerged during the work within the material research project. Thus, **Papers III** and **IV** are, to some extent, based on knowledge gained in the material research project, with the difference that the research presented in **Papers III, IV** and **V** was funded by Chalmers University of Technology.

Comparative analysis of LCA studies: Combining previous empirical data

Several research projects on LCA in R&D settings had been conducted by different researchers in the Research Group of Chemical Environmental Science at Chalmers University of Technology, and its cooperation partners; the SP Technical Research Institute of Sweden, and the University of Copenhagen. During conversations at seminars, and during lunch and coffee breaks some obstacles confronted in the LCA studies in R&D projects repeatedly came up for discussion. After some time, the need to clarify lessons learned became apparent and formal meetings were booked to discuss how to proceed. At these meetings, the six authors, all connected to the Research Group of Chemical Environmental Science, compared and discussed written descriptions of and experiences from five inter-organisational R&D projects. The author of this thesis, contributed with her experience from the material research project above. Between the main meetings, smaller meetings with two or three participants were held to discuss specific roles, R&D projects or texts. The work finally resulted in **Paper III**.

Comparative analysis of sustainability in product development at two large companies: Reanalysing existing empirical data supplemented with retrospective interviews

Two multi-national consumer product companies were selected based on the fact that both had been successful pioneers in terms of focusing on sustainability. However, the way the companies organised their sustainability efforts showed substantial differences. The research in **Paper IV** addresses the period from the start of their sustainability activities in the early 1990s until 2007. Between 2002 and 2007, the author of the thesis was an environmental specialist in product development at COMPANY

A, i.e. an insider researcher, however, in this thesis the author acts as an outsider researcher with insider insights for the period studied. The two co-authors act as outsider researchers. A team of insider and outsider researchers was identified as an effective setup, as a pure insider is too caught up in the action to practice reflexivity, and a pure outsider is not close enough to understand what is really going on (De Guerre, 2002).

One of the co-authors had earlier covered both companies as part of a comparative action research process. In total, 18 interviews had been conducted from 2005 to 2007. The third author had no previous contact with the companies but had experience from analysing management systems and sustainability in several other companies. The three authors discussed and analysed the data together using the conceptual framework suggested by Marmgren *et al.* (2012). The conceptual framework was adapted, and is described in **Paper IV** and in Chapter 2.5.

The co-authors' prior experiences were complemented with additional retrospective interviews of five individuals who were employed by the companies during the period studied. In addition, the two co-authors conducted a number of interviews along with the author of this thesis. The aim of the interviews was to verify that the results of the analysis were not misunderstood and to complement data gaps. The five interviewees had reflected on the companies' work practices, individually, prior to the interviews. One of the interviewees had worked for both of the companies.

Ecolabel impact on product development at three clothing companies: An interview-based study

Three companies were selected with the intent to cover different types of clothing with design departments located in Sweden. Four managers in the clothing design process of the three clothing companies were interviewed. The initial plan was to interview designers, but at the first contact with Company A, a designer regarded sustainability issues as beyond the scope of their job description and persistently redirected questions to the people in the company that worked with setting criteria for production, distribution and transportation. No designer was talked to in Company C, because management opinion was that designers were not interested, and therefore would have limited knowledge of sustainability. Company B was a small company, and the interviewed design manager also worked as a designer.

3.4 Reflections on the quality of research

A traditional set of quality criteria are validity, reliability and objectivity, which originally were primarily used in quantitative research designs. However, these criteria presuppose that a single absolute account of social reality is feasible (Guba & Lincoln, 1994). Instead, Guba & Lincoln (1994) have suggested the following four criteria for the trustworthiness of qualitative research designs: credibility, transferability, dependability and confirmability (Bryman & Bell, 2011). Credibility is an evaluation of whether or not there is a reasonable match between the researchers' observations and the theoretical ideas they develop (parallels internal validity). Transferability is the degree to which findings can be transferred or generalised to other circumstances (parallels external validity). Dependability is an assessment of the quality of the practice of data collection, data analysis, and theory generation, and is a parallel to reliability. Confirmability is the extent of the impartiality of the researcher's findings, and entails the awareness that complete objectivity is impossible.

Since various research approaches were used in the six papers, the fulfilment of trustworthiness varied. An overview is given in Table 3.

Table 3. *Overview of trustworthiness in each paper. Confirmability is the same for all Papers and is described at the end of Section 3.4.*

Paper	Credibility	Transferability	Dependability
I	Reflected and contrasted together with co-authors	Knowledge base for any similar project aiming to shift from petroleum-based to bio-based materials	Documented search details and results in a mindmap
II	Standardised assessment method Publicly available data	The way of using the method	Calculations are documented together with assumptions and data sources
III	Triangulation applied	Aimed to aid the setup of other R&D projects	Agendas and notes from the meetings are saved
IV	Interviews performed together with co-authors Direct feedback during the interviews Triangulation applied	The results can be useful for • companies starting sustainability work • companies evaluating their sustainability work	Transcribed notes with reflections Recorded interviews
V	Direct feedback during the interviews Feedback on the Paper Triangulation applied	The results can be useful for ecolabel organisations and design managers in developing their work	Documented search details and results in a report Transcribed notes with reflection
VI	Reflected and analysed together with co-authors	The suggested process are aimed to guide other similar PD projects	Documented the activities such as invitations, result sheets, oral feedback and reflections

Credibility issues were handled in different ways in the six papers. In the literature-based study (**Paper I**) the findings were reflected upon and contrasted with the material research project, together with the co-authors. The literature-based study in **Paper I** and the content analysis in **Paper V** are based on published material, which to some extent can be considered credible because most had been reviewed before being published. Credibility was achieved in **Paper II** by using a standardised method. The data used was also publicly available, and the aggregated data from a reference product was considered accurate enough for the study because it was a rough estimate. The credibility in **Papers IV** and **V** was secured through direct feedback during the interviews (respondent validation) on the interpretation of the responses (Bryman and Bell, 2011, p.396). The aim of the retrospective interviews in **Paper IV** was to verify that the results of the analysis of earlier interview data and experiences had not been misunderstood, and that data gaps had been complemented. **Paper V** also

received feedback from the interviewees to ensure that interpretations of responses were accurate. In addition, triangulation was achieved in different ways for the studies in **Papers III, IV** and **V**. Triangulation refers to the use of more than one approach to the investigation i.e. gathering data through several sampling strategies, the use of more than one researcher in the field to gather and interpret data, the use of more than one theoretical position in interpreting data or the use of more than one method for gathering data (Bryman & Bell, 2011; Denzin, 1970; Lincoln & Guba, 1985). Triangulation is often utilized in qualitative research to enhance credibility. The six authors in **Paper III** compared and discussed written descriptions of and experiences from five inter-organisational R&D projects. This way of using multiple data sources and perspectives to analyse a research topic meets the criteria for triangulation. The three authors in **Paper IV** discussed the outcome of the interview directly afterwards. Then the main author transcribed and added reflections. Thereafter, the notes were handed to one of the authors who fairly promptly read, added observations and reflections, and sent it to a third author who performed the same procedure. Consequently, the data was gathered and interpreted by three people, and the criteria for triangulation was satisfied. One interview in **Paper V** was done together with the author of this thesis and a co-author. The presence of multiple interviewers decreases subjective interpretation of the results from the interview and credibility is achieved. There were three authors in **Paper V** and all three analysed the interviews, thereby, fulfilling the criteria for triangulation. In **Paper VI** credibility is satisfied, because all reflections and analyses of the workshops were done by the three authors together.

Transferability in a qualitative research design refers to the possibility of making use of the findings in another company or context. **Paper I** can be viewed as a potential knowledge base for any similar project with the aim of shifting from petroleum-based to bio-based materials. The way of using data from a reference to visualise worst and best case LCAs in **Paper II**, can be transferred to other situations for which data is not yet available. One way to accomplish transferability is through a *thick description* (Geertz, 1973) of a case, i.e. by providing enough detail to allow the reader to understand the contextual the setting of the study, to see if the findings are applicable to their own reality. In-depth interviews provided a greater understanding that benefited the descriptions in the case studies in **Papers IV** and **V**. In this respect, interviews can be deemed valuable even if the number of interviews is relatively small. In the case of **Paper III**, its results are intended to be used in any R&D project, they are based on experiences from various projects, and some detail from each project is provided. The suggested approach in **Paper VI** was developed as a response to the needs

of a specific project, but the approach is described in a generalised although detailed way, along with a description of project context details. The intent of this is that this approach can provide useful input to other similar projects.

Dependability of the literature study and content analysis was addressed by documenting search details and results in a mindmap in **Paper I**, and in a report in **Paper V**. The planning documents, results as well as feedback and reflection of the sustainability activities in **Paper VI** were saved, both by the author of the thesis and on the project's document server. Emails, invitations, PowerPoint presentations, tables and mindmaps on big sheets of paper are examples of the document types saved for **Paper VI**. The Excel file with LCA estimations, including documentation of assumptions and data sources for **Paper II**, was saved by the author of this thesis. The transcribed notes with the reflections, done directly after the interviews, from all the interviews were saved for **Papers IV** and **V**. The recordings of the five complementary interviews for **Paper IV**, and the recording for one of the four interviews in **Paper V** were also saved to allow the research team to go back to the original data during the analysis. The documents about the different R&D projects in **Paper III** were publicly available, and agendas of the meetings and notes from the meetings were saved by the author of this thesis.

Confirmability means whether or not a researcher has "acted in good faith" and has tried to be aware of their own values and personal theoretical inclinations, in order to limit influence of these factors on the research. As the mindset of the author of the thesis is to understand how to attain the development of more sustainable products, she has tried to keep an open mind and to minimise interference from her own values. A specific issue was whether or not her previous industrial experience (mentioned in the Introduction, Section 3.2) could potentially result in bias, not the least because corporate cultures can be very different. However, most of the research in this thesis was conducted in research teams consisting of members with different experiences and backgrounds. The team element can, to some extent, contribute to make a researcher more aware of potential bias in research design and/or conduct and, thereby, satisfy confirmability.

3.5 Ethical considerations of methods used

Ethical issues are present in all research conducted, and in qualitative research designs, one major issue to deal with is whether or not the data collection approach can cause any harm to the participants (Bryman and

Bell, 2011 p. 128). According to Diener and Crandall (1978) ethical issues can be analysed from four main perspectives: 1) whether there is harm to participants; 2) whether there is a lack of informed consent; 3) whether there is an invasion of privacy, and 4) whether deception is involved.

To **avoid harm** to interviewees in **Paper IV** and **V** and to participants involved in activities in **Paper VI**, their names were kept anonymous and were not revealed in any external publications. The documentation was saved in an appropriate way to ensure participant anonymity.

To address the issue of **informed consent**, the invitations to the sustainability activities in **Paper VI** included background information about the activity and a description of what the material research project and its participants would gain. Similarly, the purpose of the interviews in **Papers IV** and **V** was explained both before the interview was booked, and at the beginning of the actual interview. The interviews were also ended with a description of what would happen next, and an oral approval of this was obtained.

The interviewees in the interviews in **Paper IV** were told that they did not have to answer all the questions or talk about issues they did not wish to talk about. This was to **avoid invasion of privacy**. The interviewees were also informed that they could ask questions for clarification.

Only what was claimed to be studied when setting up a workshop or interview was studied, i.e. **no deception** was involved.

A special case concerns the re-analysis of earlier collected data. In this case, the studies in **Papers IV** and **VI** were direct continuations of the earlier studies, although re-analysed in a different way and within another theoretical framework. The basic ethical obligation of not harming the participants was adhered to. Similarly, the comparative analysis of LCA studies in **Paper III** satisfied all ethical concerns in line with the way each individual study had satisfied these issues.

4. SUMMARY OF INCLUDED PUBLICATIONS

This thesis is based on the research described in three published papers, one submitted paper, one manuscript and one conference paper. These six papers are appended in full at the end of the thesis, and are referred to by Roman numerals in the text. This chapter presents a brief summary of each paper together with the paper's contributions to the thesis.

4.1 Paper I: *Changing from petroleum- to wood-based materials: Critical review of how product sustainability characteristics can be assessed and compared*

The purpose of this paper was to find a method for selecting and assessing a set of parameters for comparing the sustainability of products in early product development. The paper is based on a literature study of available approaches for the assessment of product sustainability, with a specific focus on assessing the replacement of non-renewable petroleum-based materials with renewable wood-based materials in products. The results are contrasted with needs in a material research project.

The literature study revealed a diverse number of methods that can help in assessing different product sustainability characteristics for parts of or whole product lifecycles. Numerous sustainability assessment parameters, mainly for environmental aspects, have been used or suggested in the literature. Almost all studied assessment approaches use premade lists of assessment parameters, however without advice on how to adjust them towards a more case-relevant set of parameters. Parameters are lacking in some areas along with knowledge of how to describe these missing parameters. This is, for example, the case for social progress, impacts on biodiversity and other ecosystem services.

This paper contributes to the thesis with the findings concerning the lack of assessment tools ready-to-use in early product development, and the assessment methods' lack of guidelines for how to make a case-relevant description of sustainability.

4.2 Paper II: Environmental challenges when developing renewable materials to replace non-renewable materials: Guidance from LCA studies

The purpose of this paper was to demonstrate a way of using the Life Cycle Assessment (LCA) tool to visualise challenges faced in early product development. An LCA screening approach was used to continuously visualise e.g. how much process energy and raw materials that are used in the process of developing a new material. A reference product is used as a benchmark in the paper for a new product. The new product had to perform at least as well as the benchmark product, and preferably better. This LCA-based methodology was illustrated using the example of replacing petroleum-based polymeric material with wood-based material in a product.

Developing materials for more sustainable products requires not only a shift to renewable resources or an environmental optimisation of material production processes, but also considerations of relevant sustainability aspects throughout the entire life cycle of a product, while retaining or improving product function. This demands that the material development team has an awareness of important sustainability considerations. Visualising environmental aspects of sustainability can be done using results from screening LCA studies, showing, e.g. the environmental performance of different life cycle stages and environmental impacts of different materials.

This paper contributes to the thesis with a practical example of how LCA can be used to help a development team visualise the environmental window of opportunity, and challenges for the new products before the products have been designed.

4.3 Paper III: Making the most of LCA in inter-organisational R&D projects

The aim of this paper was to clarify how to choose an appropriate role for LCA in inter-organisational Research and Development (R&D) projects, and how to plan LCA work accordingly. The experience of LCA practitioners from five specific inter-organisational technical R&D projects, in particular, was used for identifying and describing project characteristics, which are decisive for the roles LCAs can play in such projects.

The study identified possible roles for LCAs in inter-organisational R&D projects, and four project characteristics that are decisive for which roles an LCA can play: (i) the project's potential influence on environmental impacts, (ii) the degrees of freedom available for the technical direction of the project, (iii) the project's potential to provide required input to the LCA, and (iv) access to relevant audiences for the LCA results. Evaluation of these project characteristics can help project commissioners, project managers and LCA practitioners to deliberately choose appropriate roles, and plan projects for the efficient use of LCAs in inter-organisational R&D projects. Furthermore, research is warranted to find out under which circumstances other assessment tools are more suitable than LCA for fulfilling certain roles, and whether different proposed methodologies for screening or simplified LCAs are better suited for certain roles than others.

This paper contributes to the thesis with an understanding of how and why LCAs are used in inter-organisational R&D projects, as well as how to improve the use of LCA, and other environmental assessment tools, in such a setting.

4.4 Paper IV: Naturalizing sustainability in product development: A comparative analysis of COMPANY A and COMPANY B

The aim of this paper was to understand how sustainability is integrated into product development in large companies, and how this integration is influenced by the logic of their management systems. The paper had three authors and was based on their experiences as insider and outsider researchers at two large companies. A conceptual framework for understanding management systems was adapted with the purpose of analysing, interpreting and visualising these experiences.

An empirical comparison of the two large international companies showed some similarities in terms of how they have addressed sustainability. These similarities might be of particular interest for companies striving to improve their sustainability performance. However, the comparison also showed that the ways of successfully integrating sustainability into product development can be very different because of a company's history and specific management systems. Consequently, there was no best practice with which to achieve more sustainable behaviour in the examined companies. Instead, it was found that to be successful, practices must be adapted to fit with the logic of each company's existing management system.

This paper contributes to the thesis with a greater understanding of how organisational structure influences the sustainability of final products in R&D development projects.

4.5 Paper V: Ecolabels as drivers for clothing design

The connection between ecolabels and clothing design was studied to determine how strong the connection between ecolabeling and design is, and what can be improved to speed up the transformation of the garment industry in a sustainable direction. Information gathered from the literature and detailed interviews with employees of three garment companies were analysed by a comparison of life-cycle perspectives.

The connection between different ecolabels used for clothing in Sweden, and the work of clothing designers was found to be weak in all the studied cases. One major reason for this is that current ecolabel criteria mainly focuses on upstream value chain ecological and social considerations, and only rarely are criteria on the product function level, and other downstream life-cycle stages, of direct importance for designers in their work. Another reason for the weakness is the current job task of the clothing designer, which is often to create the visual appearance of a product in a way that sells, and not to drive and support actions for the required product throughout the product development process. To involve designers and their competence in creating more sustainable consumption of clothing, their mission and their work need to be organised to enable them to influence customers to buy fewer garments and take better care of them. However, if the business models of clothing companies are linked to sales volumes and production, then designers will have limited potential to design for slow fashion.

This paper contributes to the thesis with understanding from the clothing industry of enablers and obstacles to developing more sustainable clothing, as well as with the evaluation of the potential of ecolabels to guide clothing designers.

4.6 Paper VI: Insights from guiding material development towards more sustainable products

This study investigated how the early stages of material or product development projects can be guided towards more sustainable products through action research carried out in an industry - university joint material research project. Faced with current challenges in society, many companies will need to develop more sustainable products in order to continue operations in the long term. Therefore, ways of identifying important sustainability considerations in the early stages of material or product development are of importance. The paper provides a description of activities that were performed in the project in order to guide the material development process, as well as a reflection on the outcomes.

Insights from the project, aimed at providing new materials for a future product and ensuring that the future product is also more sustainable, were used to outline a team learning approach to guide such processes. To fully utilise the competence of material developers in the direction of sustainability, the whole project team must understand how considerations in their everyday development work can affect an envisioned product's sustainability performance. Guiding a material development project towards more sustainable products requires relevant and future-oriented assessment parameters. These must also be translated into parameters that are meaningful for the material developers in their everyday work. This can be facilitated with a team learning approach, in which these issues are jointly explored by the project team, e.g. through workshops in which material properties are connected with sustainability aspects of a product.

This paper contributes to the thesis with a discussion of enablers and obstacles to assessing product sustainability in early product development, and the lessons learned regarding the challenges involved.

5. DISCUSSION

The core of this thesis is to better understand enablers and obstacles to the development of more sustainable products, and to develop action competence for that purpose. The thesis is about tools for product sustainability assessment and how they can be case-relevant by applying general guidelines at the early stage of product development. The thesis is also about limits to growth and how an organisation and work practices can guide the product development process towards sustainability by creating a shared and broad system view, as well as by providing leadership for successful change. The discussion below is focused on how tools and work practices can be put to practical use and the discussion is based on what can be learned regarding action competence from the appended papers in the thesis.

5.1 Action competence for sustainable development

Sustainability is increasingly entering corporate agendas, and companies are making efforts to become sustainable, including developing products and services that are better both for the environment and for society in general (Lowitt, Hoffman, Walls, & Caffrey, 2009). Many efforts have resulted in meagre outcomes that research literature has characterised as "green washing", or questioning the ultimate motivation behind the effort (Laufer, 2003). However, there is reason to believe that many efforts have been serious attempts, but a lack of action competence (Breiting & Mogensen, 1999; Jensen & Schnack, 1997) for sustainable development is a major obstacle for businesses.

To develop more sustainable products, many companies have implemented tool-based approaches, including the use of LCA. While some companies report excellent results with tool-based approaches, others have not shown satisfactory results (**Paper IV**; Frankl & Rubik, 2000). Thus, the mere application of tools, for assessing and evaluating sustainability impacts of a company and their products, does not seem to be sufficient to make a change towards more sustainable products (**Paper VI**). One major reason identified, is that knowledge does not become actionable until the involved people are in agreement as to what the purpose really is; and knowledge can become actionable for the involved people through collaboration and team learning processes (**Paper VI**; Argyris, 1996). The abilities and efforts of the organisations and individuals who control product development are, therefore, important

aspects to consider (**Paper II, IV**). However, a product development team also needs to be aware of perspectives from other system levels throughout the entire life cycle of a final product, such as customers, suppliers and communities close to company facilities, as well as the national and/or global community. This, in turn, puts a demand on leaders to allow for and facilitate the development of action competence (Breiting & Mogensen, 1999; Jensen & Schnack, 1997) for sustainable development in their organisations in order to successfully drive the development of more sustainable products.

Sustainability entails a long-term commitment and focuses on the needs of coming generations, which conflicts with the normal time perspective of 1 to 10 years in the long-term planning procedures of companies (Leadbitter, 2002). Approaches are, thus, needed that facilitate the integration of sustainability considerations. Such an approach would include the integration of long-term considerations into early product development processes, before decisions are made. Decisions in this early stage are well known to have a profound impact on the sustainability performance of the final product (Sakao & Fargnoli, 2010); therefore these considerations must be identified (**Paper VI**). At this early stage of product development the cost of change is comparatively low (Bhamra & Lofthouse, 2007; Ramani *et al.*, 2010; Ritzén & Beskow, 2001).

Action competence is one type of competence that enables the creation of more sustainable products. The papers appended to the thesis all aim at contributing to action competence by identifying strengths and improvement areas, and by suggesting ways to visualise and increase leaders', teams' and individuals' practical understanding of and ability to develop sustainable products. The main elements in these contributions are described in the following sections. First, as a point of departure for product sustainability assessment in early product development, three elements have been identified (further discussed in Clancy, 2012):

- Relevant product sustainability considerations need to be established for every product
- Product development implies that a product system is under development and not yet clearly defined
- Sustainability assessment implies a future-oriented assessment and no-one knows what the future will look like

The fact that so much is unknown remains a challenge for a development team but also an excellent opportunity to influence the development process towards a more sustainable product.

5.2 Case-relevant versus general guidelines

Sustainability depends on the management of materials and products during their entire life cycles, rather than on certain characteristics of materials or products (Ny, MacDonald, Broman, Yamamoto, & Robért, 2006). The set of product sustainability assessment parameters that is relevant to use will, therefore, differ over time and from one product type to another, along with geographical locations and cultural contexts. Consequently, different sustainability parameters might be more or less urgent or relevant for different systems (Clancy, 2012; Marsden, Kimble, Nellthorp, & Kelly, 2010). Water, might be an important input to a production process, however, its importance, in terms of availability, purity and price, varies in different parts of the world, and will also potentially change with season and over time. Any sustainability assessment, therefore, has to be case-relevant in order to address the life cycles that are to be improved or compared in relation to their specific surroundings (**Papers I, VI**). This means that an essential element in a product sustainability assessment process is to identify what sustainability implies for the case, namely, what to include in the concern, and how to handle trade-offs and uncertainties (Munthe, 1997; Steen, 2006).

Although a sustainability assessment needs to be case-relevant, sustainability as a concept can only be universally defined on an overarching level. Therefore, it is useful to base the description on general concepts and principles like the product life cycle perspective (Baumann, 2014), cradle-to-cradle thinking (McDonough, Braungart, Anastas, & Zimmerman, 2003) and to base the description on significant general common trends, such as demographic changes in population growth and urbanisation (Kates & Parris, 2003). An example of the latter type of consideration for product development can be found in Clancy *et al.* (2010).

While it is easy to understand that case-relevant assessments can serve as a basis for actions, the general principles can also serve as guidelines for groups and individuals if managed properly (**Paper III**). For example, the four principles for sustainability (Holmberg, 1998) can guide a product developer in choosing variants of materials to use in a more sustainable product in order to develop a set of product concepts (Alänge *et al.*, 2007).

5.3 Assessments in early stage product development

The three questions that should be answered before any assessment is made (Munthe, 1997) can be formulated in the following way for a

product development project (Clancy, 2012): 1. Which sustainability issues are the most relevant? 2. How should potential trade-offs between sustainability issues be made? and 3. How should uncertainties in the product sustainability assessment be dealt with? This requires that the development team take the time at the beginning of the project to respond to these three questions together. The insights from **Paper VI** show that this is not easy to achieve in practice. This difficulty can partly be understood by relating to Ansoff & McDonell (1990) and filter theory. While the surveillance filter for obvious reasons can pose a significant hinder in a new area, as the team might simply not be aware of what is out there in terms of emerging technologies and sustainability assessment approaches, other filters also exist that hamper change processes, even when the information is accessible. First, a mental filter supports previous assumptions and contributes to a selection of assessment parameters that are known from previous experiences. Second, a power filter, which is connected to decision makers' feeling that their positions are threatened by change, can also consciously or subconsciously affect the approach that is ultimately selected. In addition, the issue of deciding on trade-offs is not easy, because existing knowledge typically does not provide a clear-cut direction. This is in line with Agryris' (1996) observations that knowledge often indicates conflicting actions, and either contradicts stated objectives, or in other ways is presented in a manner that inhibits the knowledge from being taken into account in decision making.

During early stages of product development, it is not yet known, for instance, which resources or materials will be used, how much material will be needed, where and how the materials and products will be produced, how many products will be produced and how the wastes and products can be disposed of after use. Consequently, data for the product system is not yet available. Many available assessment tools, therefore, cannot be applied to their full potential in early development stages, since they are designed for the assessment of existing products and are based on quantitative data for real processes (**Papers I, VI**). Qualitative tools based on product life cycle thinking could, therefore, be of better use in early product development (Baumann, 2014; Luttropp & Lagerstedt, 2006).

The use of quantitative tools can still be useful, but will require a creative way of using the available data and methods. An early LCA study can, for instance, be made of data generated from a scaled-up model of a conceptual production process, developed from lab scale data (Baumann & Tillman, 2004; Harding, Dennis, Von Blottnitz, & Harrison, 2007). Thereby, the magnitude of environmental challenges can be visualised and understood by team members involved in the early phases of the development work (**Paper II**). In order to develop such shared

understanding, and to facilitate decision-making, the assumptions and the results of product-sustainability assessments need to be presented in a simplified way so that the main message can be easily understood (Luttropp & Lagerstedt, 2006). This means that there is a delicate balance between the need for simplification for the purpose of communication, and conveying sufficient detail to enable an understanding of the critical assumptions made during an analysis.

Resistance to the use of preliminary process estimates for environmental assessments may be encountered from the developers when the material design has not yet progressed past the bench-test scale. Results of an early LCA assessment can be perceived as threats to innovation if they are unfavourable. Nevertheless, such preliminary calculations are important in the development of more sustainable products, since they may highlight particular challenges and initiate a dialogue about how to handle the challenges (**Paper II**). It is important to use these early results exclusively as indications based on coarse assumptions, and not to be lured into seeing them as the final word on the product's environmental performance. LCA may also be used in a continuous learning process by regularly updating the LCA study as more knowledge and data about the product system is developed (**Paper III;** Svanström *et al.*, 2014).

5.4 Limits to growth

Literature on humanity's uncertain future due to limits to growth has recurred over the decades (Alänge, 2014), e.g. Rachel Carson's Silent Spring (Carson, 1962), the Club of Rome's Limits to Growth (Meadows *et al.*, 1972), Our Common Future published by the UN's World Commission on Environment and Development (WCED, 1987) and An Inconvenient Truth written by Al Gore (Gore, 2006). Although, the issue has been discussed and questioned for a long time, it remains relevant to discuss (IPCC, 2013, 2014a, 2014b).

In a world with such resource limitations, as discussed in the references mentioned above, one important question concerning any product is whether it has the potential to fit into a sustainable society, or at least be a bridging solution that can assist in a move in that direction (Holmberg & Robèrt, 2000). However, the parameters that are perceived or experienced as the most critical for sustainability today, might be very different in the future. Thus, the envisioning of different potential futures is needed to guide the development of products (**Papers I, VI**). Presently, product assessments are most often based on the current situation, for example, on today's energy mix of fossil fuel, renewable power and nuclear power.

Therefore, these assessments do not necessarily take the future development of surrounding systems into account.

Many companies are shifting from non-renewable to renewable material resources, and expect that this will result in more sustainable products. However, the sustainability of products is a complex issue that depends on numerous factors; renewability and climate change are only two of these (**Paper I**). Changing from a non-renewable to a renewable raw material does not automatically mean that the product will become more sustainable. For example, a scenario analysis of the forest area required for a product in Europe until 2050 (Clancy *et al.*, 2010) showed that significant use of the annual European forest growth was needed for the materials used in this single product. Given the expected increase in demand for both bio-based fuels and other bio-based materials to replace petroleum-based fuels and products, the need for renewable resources for an individual product have to be analysed in the context of the need for alternative uses of the resource. In addition, this means that products are competing for either the yield from the forests or from the land area (Beland-Lindahl & Westholm, 2011). At the same time, there are increasing concerns regarding biodiversity and other ecosystem services (Costanza *et al.*, 2006; MEA, 2005). It is, thus, important to estimate future global demands on forestry, and also to visualise these results for the company's strategy and development departments (e.g. using scenarios), if biomass and/or wood is to be used in a responsible way in future products. However, considerations regarding the limitations of physical resources are often assumed to be handled at the societal level and not at the company level, although companies are the ones that are both influenced and can influence the use of resources (Baumann, 2014). Nevertheless, in order for companies to stay in business in the long term, their strategies need to include the implications of limits to growth in a way that benefits society as well as the company (Porter & Kramer, 2006).

In practice, however, estimates of in which direction a present structure will lead (Clancy *et al.*, 2010) are typically rejected, which has been described as follows:

> *Most people intuitively and correctly reject extrapolations, because the results appear ridiculous. It must be recognized, however, that in rejecting extrapolated values, one is also rejecting the assumption that there will be no change in the system (Meadows et al., 1972)*

There are factors beyond the immediate control of designers and developers that affect their possibilities of making an impact on

sustainability. For example, the investigation in **Paper V** revealed that designers' potential to steer a company towards more sustainable clothing is rather limited with business models linked to the volume of sales and production. Business models that create more sustainable consumption are seen as a threat, leading to reduced volumes and decreased profitability (Allwood, Laursen, Russell, de Rodríguez, & Bocken, 2008). To change this situation, managers of clothing companies must carefully consider new business models.

A change in business model could also give successful results for companies when considering how their products are affected by different resource limitations. For companies that want to continue on this road, a subsequent stage, after developing new business models, is described by Nidumolu *et al.* as creating next-practice platforms to which companies could move to become more sustainable. To develop such next-practice platforms, a company also needs to analyse and to consider the simultaneous development of other actors in their innovation system, in order to realise the change (Alänge & Fogelberg, 2014). This is in line with the demands of sustainability as a systems approach to development, and it also emphasizes the importance of including the company as an essential actor, thus enabling the creation of a mutual advantage both for society and the company (IPCC, 2014a; Porter & Kramer, 2011).

5.5 Creation of action competence for development of more sustainable products

Strategies that aim for more sustainable products provide great opportunity for radical product improvement and innovation to achieve a high level of sustainability (Nidumolu et al., 2009). Radical improvements require collaboration in teams, over system levels and between organisations. New business models could be a result of such collaborations. Such creation of action competence for the development of more sustainable products also puts high demands on decision makers and other leaders in the process.

Shared and broad system view for action

Product developers can strongly affect the sustainability performance of a final product. Providing developers with parameter results to improve on will, however, not automatically free them to use their competence towards the development of a more sustainable final product. To make it possible for them to rethink and make a more sustainable final product, developers need to know of *and* understand which surrounding world

and future-oriented considerations that have significant impacts on the product's sustainability performance. The developers also need support in translating and integrating relevant parameters into something that can guide them in their area of expertise (**Paper VI**).

Designers can also potentially influence the sustainability of products in a major way (Sakao & Fargnoli, 2010). They need input that helps them define what a sustainable product is, and positive motivational influences to work in this direction. One potential input would be to make the link to eco-labels visible for designers. However, the study presented in **Paper V** shows that in the case of clothing design, there is currently a very weak connection between eco-labels and the clothing designer´s work. This lack of connection is mainly because eco-label criteria focus on ecological and social considerations in the supply chain, and only rarely on criteria on the product level such as life span or aspects of use. Since the present main focus of product sustainability improvements most often revolves around incremental improvements of current product systems, improvements in the supply chain is also closer at hand. However, broader system perspectives are needed to achieve a high level of sustainability, and, here, designers could potentially make a contribution (Waage, 2007).

Establishing shared vision, including a broad system perspective, and relevant product sustainability parameters requires trust, collaboration and team learning processes (Edmondson & Nembhard, 2009; Hardi & Zdan, 1997; ISO/TR 14062, 2002). These processes take time and will demand even more time as inter-organisational projects increase. Various activities on the project level can provide input to the development of this process, i.e. guiding product development, as well as provide input to the product sustainability assessment itself (**Paper VI**). Experiences from such activities emphasize the challenges involved in interacting with the different groups in an organisation, e.g. in terms of motivating the development team and in providing them with meaningful information. The challenge of motivating the development team and the difficulty in comparing different types of considerations verify the importance of having a shared vision, and establishing relevant sustainability considerations for each product development project. The necessity of having managers that support the process (Ansoff & McDonnell, 1990), and a process that generates the commitment of team members to participate (Mullen & Copper, 1994) is clearly evident in the activities studied in **Paper VI**.

Leadership for successful change

What leaders do is an important part of action competence in a company. To successfully integrate a shared vision or to affect a changed behaviour, such as increased sustainability thinking in an organisation, requires understanding how change can be created in the organisation, and how the specific organisation's management system influences behaviour. This is generally omitted in project management today although inter-organisational projects, in which this understanding is of even greater importance, are increasing.

For product sustainability assessment to have an influential role in an inter-organisational R&D project, the assessment needs to have the potential to impact sustainability, because, otherwise, it will not be prioritized by the R&D project (**Paper III**). To achieve this, the assessment must answer the relevant questions for the R & D project's members. (**Papers III, VI**). However, if project members do not even realise that the assessment is relevant, sustainability considerations becomes not only a matter of communication, but also an issue for the leadership of the project organisation. A leadership that cares about developing people and teams is needed, therefore, a laissez-faire leadership can be detrimental (Lewin *et al.*, 1939). In addition, the R&D project needs to have the mandate to change the product system, which, once again, is an issue for the leadership of the project organisation. Sustainability assessors, thus, need to consider different types of audiences, and adjust their communication according to audience needs **(Paper III),** since, for example, an R&D project's needs are most often different from the needs of leaders and/or decision-makers.

Even among companies with substantial experience of working with sustainability issues and that are considered successful in their work with sustainability, approaches can be very different (**Paper IV**). This is in line with the discussion of 'equifinality' (Drazin and Van de Ven, 1985), i.e. the principle that in open systems, a given end state can be reached by many potential means and routes, which in turn means that there are multiple ways to reach a more sustainable work practice. In the study reported in **Paper IV**, it was found that this difference in approaches to sustainability can be understood as a reflection of each company's history and the logic of each company's culture and management system.

The study reported in **Paper IV**, shows that the style of leadership can be very different in different companies. The leadership style in one company was based on the founder's values and basic ideas for the company, which mobilises the company toward a common vision and focuses on end-customers, leaving the means to reach this objective up to each individual.

This culture was reinforced by 'story telling' about the founder's choices and behaviour, which has remained consistent over the years, and with which official documentation and oral communication are in congruence. The values in this company create emotional bonds that bring a feeling of belonging to the organisation, which creates employees who feel responsible for the whole business. The aim of the leadership is to build lasting personal strengths that make the company more successful overall. Thus, individuals' long-term experience with the company is highly valued. In a company that emphasises its culture, employee socialisation and individual creativity, the selection and hiring of new employees is crucial (Steiber & Alänge, 2013). The standard practice has been to develop co-workers originally hired to work on the shop floor into leaders. Only recently has this long-term strategy of internal leadership development been complemented by hiring competent leaders from the outside.

The leadership style in another company was built more on compliance with the company's written documentation. The written documentation and instructions were decisions on what and how to do things, but typically based on a process of consensus. The leaders expected excellence and self-direction in accordance with the written documentation. Thus, expertise was highly valued and most employees had a university degree. Knowledge was enhanced in collaboration, and there were diverse networks with outside actors within the employee's area of expertise. Prestige and career thinking, i.e. competition, was a driving force for excellent employees in the company, which could cause hesitation in sharing information. In this context, individuals were hired as experts into specific fields of expertise, which fits the prevailing management model.

In the first company, innovation is facilitated by the culture of the company that strives to assure its employees that they can contribute to customer satisfaction, and that everything is possible through their initiatives. The other company can introduce change quickly through formal decisions and documentation, because the connection between documented communication and behaviour is strong (**Paper IV**).

As Goleman (2000) pointed out, there is not one preferred leadership style in every organisation. Instead, Goleman has shown that a collection of leadership styles can be used in a flexible way to achieve a pleasant climate and advantageous business performance. However, as shown above, there are distinct differences between the two case companies, depending on the prevailing management systems **(Paper IV)**. It is worth noting that both companies have been successful and are seen as role models for integrating sustainability, however, they achieved this objective in different ways.

5.6 Concluding remarks

The tools available contain many useful elements and approaches that can assess different attributes or articulations of product sustainability for parts of or whole product life cycles. However, to understand when and how to use these tools it is necessary to establish case-relevant sustainability assessment parameter sets. The process of establishing such parameter sets takes time and requires the collaboration of many different actors, in which the first step is to attain a shared view of which sustainability concerns to consider. Every project is, to some extent, unique, thus, using product sustainability assessment tools to guide in early product development requires the selection of general tools which are then adjusted to the relevant product considerations and to the people involved throughout the entire process. This can be viewed as a continuous learning and improvement process.

In early product development, before decisions for a final product are made and when the cost of change is low, the opportunity to influence towards a more sustainable product is at its greatest. To make it possible for a product development team to use their competence, to rethink and move towards a more sustainable final product, they need to know of *and* understand which surrounding world and future-oriented considerations make significant impacts on the product's sustainability performance. However, to create this action competence, it is necessary that managers support the process and that team members are committed to participation in the process. This might prove difficult, but can be facilitated by creating sustainability approaches that fits each company's culture and management system.

6. CONCLUSIONS

Parameters presently utilised in product sustainability assessments are mainly focused on the production stage and on environmental sustainability. Although efforts have been made to include other sustainability considerations and life cycle stages, not much of such efforts are utilised in practice or has even been tested in real case studies.

Environment assessment tools can be utilised to guide the early stages of product development processes. However, these tools need to be adapted to specific circumstances, such as the limited availability of data for products under development, and to assessment parameters identified as the most relevant for the case at hand.

Enablers and obstacles present in company work practices for the development of more sustainable products are different in different companies. For organisations to effectively work with the development of more sustainable products, it is vital to enhance action competence for sustainable development in the organisation. Team learning can be an important tool to achieve action competence, if used in line with the management system in each company.

The integration of sustainability considerations into product development must, to be successful, be adapted to the management system of each company. Regardless of how sustainability considerations are integrated, the product development team needs leadership that both supports the process and provides positive motivational impulses for the work.

The research revealed that technical knowledge on products, production and sustainability is a necessary condition, but by itself not sufficient to drive development of more sustainable products, action competence is needed. For a company or organisation to achieve action competence, collaboration and team learning are necessary, since many different skills must be utilised.

7. RECOMMENDATIONS FOR FURTHER RESEARCH

There is a need to better understand how different contexts influence the sustainability of a final product.

The two research fields; assessing product sustainability and understanding organisational change for sustainability, need closer interaction. Today, research in the border area between these two fields is hampered by such simple things as that the researchers in the two fields have very different vocabulary and discussion focus. One special issue of interest, that needs to be considered from both perspectives, is how new business models can influence product development and change organisational behaviour.

Another interesting issue would be to further explore how to efficiently and creatively utilize existing data to illustrate the environmental *window of opportunity and challenges* for products that have not yet been designed.

To promote innovation towards more sustainable products, studies are needed on how to guide innovative processes. Case studies should be conducted in order to define barriers and to determine how to overcome them. Research is needed on how to set up development projects of this type, in order to encourage a long-term perspective and learning. Project setups with predetermined deliverables may not be suited for some research and development projects, since such an approach may limit learning by preventing the utilisation of new knowledge and understanding gained in the project.

Let's

Celebrate
This party's over
I'm going home

- An Emotional Fish

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