Brokering Ecodesign Practices

Industrial PhD in Siemens Wind Power

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INDUSTRIAL PHD WITH SIEMENS WIND POWER

BY
KRISTEN SKELTON

DISSERTATION SUBMITTED 2017

AALBORG UNIVERSITY
DENMARK

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Dissertation submitted

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Front cover image: Lillgrund in the Øresund between Malmö and Copenhagen. The wind farm consists of 48 SWT-2.3-93 Siemens wind turbines and is operated by Vattenfall.

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CV

Kristen Skelton (Ontario, Canada, 1983) obtained her Master of Science in Corporate Environmental Management from the University of Jyväskylä in Finland in 2010 and her Bachelor of Environmental Science (Honours) from the University of Waterloo in Canada in 2007. She began her professional career as an environmental specialist in January 2011 with the Wind Power and Renewables Division of Siemens AG. April 2011 marked the onset of this Industrial PhD project with Siemens Wind Power and the Department of Development and Planning at Aalborg University. Kristen remains employed with the company, now Siemens Gamesa Renewable Energy, and represents the company on WindEurope’s newly formed Sustainability Task Force. She hopes to continue her collaboration with Aalborg University going forward.

SUMMARY

The central focus of this research concerns the integration of ecodesign in a manufacturer of wind turbines. The introduction of environmental aspects into design processes dates back to the 1970s but ecodesign officially emerged as a concept in the 1990s, and has been applied in the design and development stages for improving the environmental performance of products, services and technologies. The concept correlates with the twelfth UN Sustainable Development Goal for responsible consumption and production and is considered a mature subject based on three decades of research and industry practice. Despite this, and the number of guides and standards that have been developed to facilitate integration in companies, adoption challenges inside the enterprises remain prevalent and continue to be the focus of investigation. Integration and adoption barriers are associated with a predominant focus on technical tools and formal procedures rather than social practices, otherwise designated the "soft" side of ecodesign.

This research is a result of an Industrial PhD in collaboration between the research group on Sustainability Innovation and Policy at Department of Development and Planning, Aalborg University and the Wind Power and Renewables Division of Siemens AG (now known as Siemens Gamesa Renewable Energy). From a pragmatic research tradition, the central research question explored is:

> *How can ecodesign be cultivated in Siemens Wind Power in a way that incorporates both formal procedures and social practices?*

More specifically, the research investigates how environmental aspects can be integrated in the product design and development activities of the company and contributes to the debate around the value of the "soft" side of ecodesign and change management. Tools such as life cycle assessment and organizational procedures do not generate the necessary conditions for integrating eco-design into product development. The conceptual principles of Wenger's (1998) communities of practice are used as a theoretical foundation to highlight the importance of social factors such as stakeholder participation and situated learning, and also to demonstrate practical measures and considerations on how ecodesign communities of practice can be cultivated.

A design-based research framework was applied to articulate how the research was performed and analysed. The research process was guided through the use of four qualitative methods: engaging in practice, literature and document reviews, semi-structured interviews and workshops. A series of full-scale LCAs were also performed with two other industrial PhD students.

The analysis is divided into three parts outlined below and includes six manuscripts for academic journals (cf. list of publications). Additional outcomes especially related to the company are: an ecodesign procedure, a series of environmental product declarations (EPDs) and a research note for WindEurope which are provided in the appendices.

Part 1. Conceptual frame: contains the state-of-the-art in ecodesign practice and principles related to communities of practice which are theoretically based on situated learning. Part 1 also includes the first article about the drivers and barriers to ecodesign based on a combined literature review and series of semi-structured interviews with seven European multinational companies. Key findings from this part include:

- External partnerships and motivated employees are two drivers that should be nurtured to initiate and sustain ecodesign practices.
- Employees have an essential role as brokers for coordinating and facilitating between internal and external communities of practice.
- Boundary objects are effective means for establishing dialogue, encouraging participation, securing management buy-in and improving situated learning around ecodesign.

Part 2. Contextual frame: represents the company and industry characteristics, which had an influence on how the research was carried out. External conditions within the wind industry, product specific information about wind turbines as well as the company's organizational structures and practices as they relate to product development and environmental management are all described and analysed in this part. The second article characterises in greater detail, the degree of life cycle thinking and stakeholder participation in the company's product development process. The main findings from this part include:

- The company is in a constant state of change and this correlates to the maturing wind industry in which it operates. Both environmental and product development practices are being continuously revised to reflect the wind industry developments and other industries' best practices.
- Although environmental practices are deemed relevant and synchronous with existing product development practices, there are nevertheless improvement potentials. One example is emphasizing the social pillar of sustainability and the company's fundamental purpose for delivering social value. A second example is engaging stakeholders earlier in the development process, particularly external stakeholders.
- Project management, sales and strategy functions were identified as potential internal functions that could help to leverage environmental practices in the Technology functions.

Part 3. Ecodesign solutions: comprises the outcomes from the empirical research, where artefacts were developed, integrated, evaluated and refined over a number of participatory iterations. The remaining four articles are included in this part. The third article describes the iterations used to develop and implement the ecodesign procedure in the early part of the PhD. The fourth article provides an analysis of how the principles of communities of practice can be used as a framework for practicing ecodesign. The fifth article investigates Siemens' sustainability engagement practices with customers while the sixth article uses the management of composite waste from blades as point of departure to evaluate Siemens' participation in industry based sustainability networks. Key findings from this part include:

- A participatory approach that was simple in the beginning but based on continuous improvements enabled adaptive learning amongst employees.
- Siemens Wind Power is a learning organization within a maturing industry and future focus should be predominantly on community based practices rather than procedures. Workshops and communication around ongoing environmental and product development activities are effective methods and should be used more frequently.
- Siemens Wind Power has a perceived advantage to other industrial manufacturers because they offer "green" products of overall value to society. Customer and societal expectations are likely to increase in this regard so this claim should be more integrated as part of the core philosophy and operational culture.

The overall finding of this research is that an initial foundation for ecodesign practices was cultivated in Siemens Wind Power. A formal ecodesign procedure and numerous artefacts were developed. Their use as boundary objects in real design projects proved valuable for negotiating meaning across different organizational communities. Engagement in practice as a methodology and brokering built internal capacities and supported adaptive learning around life cycle thinking.

Readers are left with two critical points of reflection: Firstly, ecodesign procedures and artefacts are not crucial for driving environmental improvements. If companies operate with the conviction to create social value and business-as-usual practice was to think safety, environment, quality and cost in all operations, then normative procedures could be reduced or avoided all together. Peter Drucker's quote thoroughly embodies this:

> *"Culture eats strategy for breakfast, operational excellence for lunch, and everything else for dinner!"*

Secondly, companies should embrace extended producer responsibility and leverage their stakeholders by "shaking" them into creating social value to advance common sustainability goals. If embraced, strategic partnerships and mutual industry benefits could be fostered.

RESUMÉ

Det centrale fokus i denne afhandling handler om integrering af ecodesign hos en vindmølleproducent. Integrering af miljø i designprocesser går helt tilbage til 1970'erne, men ecodesign brød for alvor igennem som koncept i 1990'erne og har siden været anvendt i design- og produktudvikling med henblik på at forbedre miljøpræstationen af produkter, services og teknologier. Konceptet er relateret til FN's 12. verdensmål for bæredygtig udvikling omhandlende ansvarligt forbrug og produktion, og anses som færdigudviklet baseret på tre årtiers forskning og industriel praksis. Til trods herfor samt til trods for et anseligt antal guidelines og standarder udviklet for at facilitere integreringen i virksomheder, så er udfordringerne stadig fremherskende. Barrierer for integration og tilegnelse er knyttet til et altoverskyggende fokus på tekniske værktøjer og formelle procedurer frem for den sociale praksis omkring design og produktudvikling, også betegnet som den "bløde" side af ecodesign.

Denne afhandling er et resultat af en erhvervs Ph.d. udarbejdet i samarbejde mellem forskningsgruppen Bæredygtighed, Innovation og Politik under Institut for Planlægning, Aalborg Universitet og Wind Power and Renewables Divisionen i Siemens AG (nu Siemens Gamesa Renewable Energy).

Ud fra en pragmatisk forskningstradition er det centrale spørgsmål for undersøgelsen følgende:

Hvordan kan ecodesign kultiveres i Siemens Wind Power med henblik på at forankre i såvel formelle procedurer som sociale praksis?

Mere specifikt undersøges i afhandlingen, hvordan miljøforhold kan integreres i produktdesignet og i virksomhedens udviklingsaktiviteter, og hensigten er desuden at bidrage til debatten om værdien af den "bløde" side af ecodesign samt måden hvorpå ændringer håndteres. Værktøjer som for eksempel livscyklusvurderinger (LCA) og organisatoriske procedurer skaber ikke i sig selv de nødvendige betingelser for integration af ecodesign i produktudviklingen. De begrebsmæssige principper i Wengers (1998) praksisfællesskaber benyttes som teoretisk grundlag til at fremhæve væsentligheden af sociale faktorer, herunder inddragelse af interessenter og situeret læring, samt til at demonstrere praktiske foranstaltninger og nødvendige hensyn i forhold til, hvordan ecodesign fælleskaber kan kultiveres.

En design-baseret forskningsramme er blevet anvendt som grundlag for undersøgelserne og analysen i afhandlingen. Undersøgelserne er karakteriseret ved brugen af fire kvalitative metoder; nemlig deltagelse i praksis, litteratur- og dokumentstudier, semistrukturerede interviews samt workshops. En serie af LCA studier i fuld skala blev udført i samarbejde med to andre erhvervs Ph.d. studerende.

Analysen er inddelt i tre dele jævnførende nedenfor og omfatter seks videnskabelige artikler (jf. listen over publikationer). Supplerende resultater særligt relateret til virksomheden er herudover; en procedure for ecodesign, en serie a miljømæssige produktdeklarationer (EPDs) og et forskningsnotat for WindEurope som fremgår af bilag.

Del 1. Konceptuel Ramme: Indeholder nyeste ecodesign praksis og principper relateret til praksis fællesskaber, som er teoretisk funderet i situeret læring. Del 1 omfatter også den første artikel omhandlende drivkræfter og barrierer for ecodesign baseret på en kombination af litteraturstudier og semistrukturerede interviews med syv Europæiske, multinationale virksomheder. Væsentlige konklusioner fra denne del omfatter:

- Eksterne samarbejdsaftaler og motiverede medarbejdere er to drivkræfter som bør næres til at indlede og vedligeholde ecodesign praksisser.
- Medarbejdere har en væsentlig rolle som mæglere i koordineringen og faciliteringen mellem interne og eksterne praksis fælleskaber.
- Grænseobjekter er effektive redskaber til at skabe dialog, fremme deltagelse, sikre ledelsens støtte samt forbedre situeret læring om ecodesign.

Del 2. Kontekstuel ramme: Beskriver og analyserer virksomhedens og industriens karakteristika, som har påvirket hvordan undersøgelserne blev udført. Eksterne forhold i vindenergiindustrien, produktspecifikke informationer om vindmøller samt virksomhedens organisatoriske struktur og praksis relateret til produktudvikling og miljøledelse beskrives og analyseres alle i denne del. Den anden artikel karakteriserer mere detaljereret graden af livscyklus tankegang samt deltagelse af interessenter i virksomhedens produktudviklingsproces. De primære konklusioner fra denne del omfatter:

- Virksomheden er i en konstant tilstand af ændring, hvilket hænger sammen med udviklingen indenfor vindenergi, som den branche virksomheden fungerer indenfor. Både miljø- og produktudviklingspraksis undergår kontinuert revision og ændringer for at afspejle branchens udvikling samt inddrage god praksis fra andre industrier.
- Selvom miljømæssige praksisser anses for at være relevante og synkrone med den eksisterende produktudviklingspraksis, er der ikke desto mindre potentialer for forbedringer. Som eksempel fremhæves den sociale søjle af bæredygtighedsbegrebet, og virksomhedens fundamentale formål om at bibringe social værdi. Et andet eksempel er at engagere interessenter tidligere i udviklingsprocessen, særligt de eksterne.
- Projektledelses-, salgs- og strategifunktioner blev identificeret som potentielle interne funktioner som kunne hjælpe med at løfte miljøpraksis i de teknologibaserede funktioner i virksomheden.

Del 3. Ecodesign løsninger: Omfatter resultaterne af de empiriske undersøgelser, hvor løsninger blev udviklet, integreret, evalueret og forfinet over en række participatoriske iterationer. De resterende fire artikler indgår i denne del. Den tredje artikel beskriver de iterationer, som er benyttet til at udvikle og implementere ecodesign proceduren i Ph.d. projektets tidlige stadie. Den fjerde artikel er en analyse af, hvordan principperne for praksisfælleskaber kan benyttes som ramme for at praktisere ecodesign i virksomheden. Den femte artikel undersøger Siemens' praksis og relationer til kunderne i forhold til bæredygtighed. Mens den sjette artikel anvender håndteringen af kompositaffald fra vindmøllevinger som udgangspunkt for at evaluere Siemens' deltagelse i industribaserede bæredygtighedsnetværk. Væsentlige konklusioner fra denne del omfatter:

- En tilgang som baseret på deltagelse var enkel i begyndelsen, men baseret på kontinuerte forbedringer, sikrede tilpasset læring blandt medarbejdere.
- Siemens Wind Power er en organisation i læring i en industri under udvikling, og hvor fremtidigt fokus bør være rettet primært mod fælleskabsbaseret praksis fremfor procedurer. Workshops, fokusgrupper og kommunikation om igangværende miljø- og produktudviklingsaktiviteter er effektive metoder og burde anvendes oftere.
- Siemens Wind Power har en potentiel fordel i forhold til andre industrielle produktionsvirksomheder da de tilbyder et "grønt" produkt med en klar værdi for samfundet. Kundernes og de samfundsmæssige forventninger forventes at stige i denne forbindelse, og derfor bør den samfundsmæssige værdi i form af omstillingen til et bæredygtigt energisystem være en mere integreret del af kernefilosofien og af kulturen.

Det overordnede resultat af afhandlingen er, at grundlaget for en praksis omkring ecodesign blev opdyrket i Siemens Wind Power. En formel ecodesign procedure og talrige tilknyttede "værktøjer" blev udviklet. Ligesom deres brug som grænseobjekter i faktiske designprojekter viste sig at have værdi i forhandlinger af betydning og forståelse blandt forskellige praksisfællesskaber i organisationen. Engagement i praksis som metode og formidling opbyggede de interne kapaciteter og understøttede adaptiv læring omkring livscyklustankegangen.

For læseren er der to tilbageværende kritiske refleksionspunkter: For det første, ecodesign procedurer og tilhørende værktøjer er ikke altafgørende for at skabe miljøforbedringer. Hvis virksomheder drives med en overbevisning om at skabe social værdi og såfremt den daglige praksis er at tænke på sikkerhed, miljø, kvalitet og omkostninger i alle aktiviteter, så kan regler og procedurer minimeres eller undgås helt. Følgende citat tilskrives Peter Drucker:

"Kultur spiser strategi til morgenmad"

For det andet, virksomheder har et "ekstra" udvidet producentansvar i form af at påvirke og "ruske" interessenterne til at skabe social værdi og dermed fremme verdensmålene for bæredygtighed. Herigennem kan der skabes og opdyrkes strategiske partnerskaber og fælles industrielle fordele for vedvarende energi branchen.

ACKNOWLEDGEMENTS

This project has been an exciting experience beyond my imagination. Like most however, my path to completion was neither steady nor straight. But with support from many, I was able to complete it. I'd therefore like to express my gratitude to all those who made this work possible and enjoyable.

At Aalborg University I have been part of the Sustainability, Innovation and Policy research group that is composed of many engaged researchers who contribute to the development of sustainability through innovative and applied research. I would like to acknowledge these colleagues for their feedback and interest in my project. I would like to especially thank my supervisor Professor Arne Remmen who invited me back to Denmark and suggested I embark on a PhD. I appreciate his guidance in my development as a researcher and our vibrant conversations that are based on his vast experience motivating Danish companies to engage in sustainability. A special thanks also goes to Tine H. Jørgensen for her mentorship throughout the initial phases of my research. Without her drive and engagement this project would have never been initiated.

From Siemens Wind Power, I'm especially appreciative to my fellow industrial PhD sister and brother, Alexandra Bonou and Jonas P. Jensen, with whom I have closely collaborated, discussed and refined the ideas put forward in this report. Our theses should be read as a trilogy! I am indebted to my manager Karin Borg for the compassion and freedom she's provided me during this research process. Special thanks are also extended to the many past and present Siemens colleagues, especially those in the former Global Blades QM&EHS and Division EHS functions. It has been an inspiring work environment and a friendly social environment.

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Lastly, I thank my family and friends for their unreserved love, patience and encouragement. Particular gratitude goes to Lars for enduring me and being my compass on a journey that has not always taken the most direct route towards its destination.

Kristen Skelton
October 2017

LIST OF PUBLICATIONS

Articles included in the thesis and corresponding chapter:

Skelton, K., Pattis, A. and Lindahl, M. (2017) Review of factors influencing ecodesign and an organizational development framework to support implementation. Submitted to Journal of Cleaner Production. Chapter 4

Skelton, K., Bonou, A. and Remmen, A. (201x) Sustainable innovation in the design of wind turbines: challenges from a stakeholder and life cycle perspective. *Draft manuscript.* Chapter 6

Bonou, A., Skelton, K. and Olsen, S.I. (2016) Ecodesign procedure for developing wind turbines. *Journal of Cleaner Production, 126, 643-653.* Chapter 7

Skelton K., Huulgaard R.D., Schmidt K. (2016) Understanding ecodesign through a communities of practice perspective. *International Journal of Environmental Technology & Management, 19(1), 40-58.* Chapter 8

Skelton, K., Jensen, J.P., Jones, G., Burnette, S., Williams, S.P. (2017) B2B engagement for sustainable value (co)creation in the wind energy industry. *Submitted to Industrial Marketing Management.* Chapter 9

Jensen, J.P., Skelton, K. (2017) Wind turbine blade recycling: experiences, challenges and possibilities in a circular economy. *Submitted to Resources, Conservation and Recycling.* Chapter 10

The answer, my friend, is blowin' in the wind,
the answer is blowin' in the wind…

– Bob Dylan

CONTENTS

INTRODUCTION

1 INTRODUCTION

Driven by population growth and improving living standards, consumption and production systems significantly threaten our environment and well-being in terms of increasing pollution, emissions and resource demands. These modern production and consumptions systems are based on the concept of economic growth and follow a linear “take, make, waste” paradigm (Doppelt 2012) which is no longer viable on a planet that is characterised as a closed system with finite resources. Elkington (2006) outlines five environmental pressure waves associated to a number of megatrends and describes how our perceptions of sustainability have evolved over time and how their relation to the environment is transitioning our systems.

At the governmental level, the European Union has adopted a growth strategy that supports the shift towards a resource efficient, low carbon economy (European Commission 2017a). A range of sustainable consumption and production (SCP) policies at EU and national levels have been proposed for improving the environmental performance of products throughout their life cycle and increasing the demand for more sustainable goods and production technologies, while also helping consumers make informed choices (European Commission 2016). Most recent, Europe’s Circular Economy Action plan promotes a shift away from the linear economy towards a closed loop system based on efficient resource use and waste minimization (European Commission 2017b).

At the industry level, companies have adopted a spectrum of sustainable business practices over the past five decades (Adams et al. 2012; Pigosso et al. 2015). Initial passive and reactive approaches such as end of pipe technologies and cleaner production have been replaced with more preventative and proactive approaches such as ecodesign, sustainable supply chain management, product-service systems and circular economy. These latter approaches have a more product oriented focus and are rooted in systems thinking. Examples of this include the more than 300,000 certifications to ISO 14001 in 171 countries globally (ISO 2016), the 8,041 companies in 170 countries that have signed the UN Global Compact (UNGC 2015), the more than 100 manufacturers and retailers participating in The Sustainability Consortium for greening consumer goods (TSC 2017), as well as more than 100 companies collaborating in The Circular Economy 100 for closed loop business models (Ellen MacArthur Foundation 2017).

As a proactive business practice, ecodesign is used in the design and development stages for improving the environmental performance of products, services and technologies, hereafter referred to as products. Ecodesign is defined by ISO 14006:2011 and understood in this research as:

> *"The systematic integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a products life cycle"* (ISO 2011, p.2).

Ecodesign correlates with the twelfth UN Sustainable Development Goal for responsible consumption and production and is considered a mature subject based on three decades of research and industry practice (Brezet & van Hemel 1997; Pigosso et al. 2015). A number of guides and standards have been developed to facilitate integration in companies (Brezet & van Hemel 1997; ISO 2002, 2011; McAloone & Bey 2000; Tischner et al. 2000). Despite these, industrial barriers to integration remain prevalent and continue to be the focus of investigation (Bey et al. 2013; Dekoninck et al. 2016; Rossi et al. 2016) which is a contradiction to the maturity claim.

A number of works (Brones et al. 2016; Johannson et al. 2007) correlate integration challenges to a predominant focus on technical tools and formal procedures rather than social practices, otherwise designated the "soft" side of ecodesign (Boks 2006). Stone (2006a) stresses the importance of taking a humanistic rather than mechanistic approach and asserts that procedures and tools do not generate the necessary change for integration. Change management has been a growing phenomenon in ecodesign research (Brones et al. 2016; Lozano 2012; Verhulst 2012; Verhulst et al. 2007). Two social practices have been deemed important for change: participation and learning (Verhulst et al. 2012). Furthermore, Stone (2006b) informs of a lack in social structures to support reflective learning and thereby environmentally oriented change in companies.

The central focus of this research is the integration of environmental aspects into the product design and development activities at Siemens Wind Power. There is a dual intention to improve ecodesign practices in industry and also advance the "soft" side of ecodesign research. The conceptual principle of Wenger's (1998) communities of practice theory, which is based on situated learning, is used as a theoretical foundation. It is proposed that communities of practice principles can be applied in Siemens to foster ecodesign integration and by emphasizing the interplay between social practices such as participation and learning and the formal organizational structures and technical tools such as life cycle assessment. The context of the problem is summarized in Figure 1-1. I continue this chapter by elaborating on the research scope and research questions in section 1.1 and by outlining the thesis structure in section 1.2.

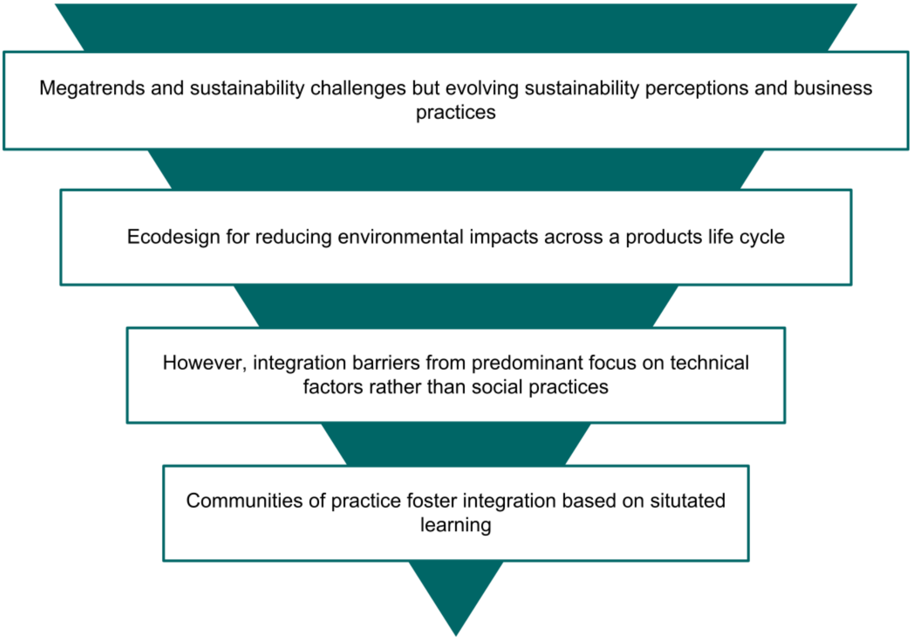

FIGURE 1-1. PROBLEM CONTEXT

1.1. RESEARCH DELIMITATION

This research is the outcome of an Industrial PhD (ErhvervsPhD) that was equally funded by Innovation Fund Denmark (Innovationsfonden) and Siemens Wind Power A/S. Innovation Fund Denmark (2016) defines this kind of PhD as:

> *"An industrially focused research project and PhD education which is carried out in collaboration with a company, an Industrial PhD candidate and a university"*.

Throughout the program:

- The candidate carries out applied research in an enterprise setting, gaining both academic and professional experience.
- The company gains a candidate to carry out the research that leads to research based commercial gains.
- The company and university alike strengthen their collaborative relations with one another.
- Innovation Fund Denmark strengthens its industry partnerships and new research foundations are created (Innovation Fund Denmark 2016).

As an Industrial PhD candidate, I am employed by the Wind Power and Renewables Division of the German engineering and electronics conglomerate, Siemens AG. Hereafter, referred to as Siemens Wind Power (SWP)[1]. SWP supplies wind energy technologies and services that combat the adverse effects of climate change. It is a project based organization so the company designs and manufactures wind turbines while also providing services across the products life cycle e.g. project planning, installation and commissioning, maintenance, repair and decommissioning.

At the same time, I've been enrolled in the Department of Development and Planning at Aalborg University with the Sustainability, Innovation and Policy research group. My tasks were allocated between PhD and company related tasks. This collaboration began in spring 2011 and continues to date. As a result, research questions have to be answered in addition to the fulfilment of business objectives in this project. I begin by outlining the business objectives. These in combination with the context of the problem (cf. Figure 1-1) are then used to formulate the research questions.

1.1.1. BUSINESS OBJECTIVES

There were three commercial reasons why SWP sought this collaboration:

Mandatory corporate standard: Prior to the onset of this research, SWP's environmental practices were mostly limited to traditional cleaner production. The corporate environmental function in Siemens AG expected that all Divisions expand their environmental scope and focus on product related environmental activities. They published a mandatory corporate standard titled *Siemens Norm 36350: Environmental Compatible Product Design* (Quella 2001) which served as the foundation for my work.

Increasing customer demands: SWP began experiencing a growing interest from customers for more transparent environmental documentation. Customers began requesting life cycle assessment (LCA) data and environmental product declarations (EPDs) in the tender phase. Concerns also started to emerge around the use of permanent magnets and the management of composite waste from the wind turbine blades.

Limited life cycle knowledge: There were no processes or tools for ecodesign in SWP which contributed to the lack of knowledge about the environmental impacts of different designs. Life cycle thinking (LCT) in product development was not customary and the products' aspects and impacts were not consciously managed.

[1] In December, 2016 Siemens Wind Power was carved out of Siemens AG and it merged with the Spanish Gamesa Technology Corporation in April, 2017.

The business objectives for SWP derived from this were:

- Comply with the mandatory corporate standard by developing and integrating company specific ecodesign procedures or tools to encourage “greener” design.
- Develop product related documentation to satisfy current customer demands and anticipate future ones.
- Improve employee knowledge about the products’ environmental impacts and LCT.

Focus was thus given to the product development process and design practices with the assumption that if they became “greener”, then “greener” product innovations would emerge.

1.1.2. RESEARCH QUESTIONS

Considering the business objectives and research gap related to integration barriers, the central research question of the thesis is formulated as follows:

> *How can ecodesign be cultivated in Siemens Wind Power in a way that incorporates both formal procedures and social practices?*

A number of sub-questions were also devised. These are illustrated in Figure 1-2 along with the main research question and business objectives. The research is divided into three parts: conceptual frame, contextual frame and ecodesign solutions. Collectively, the research questions and sub-questions provide the rationale for the design and conduct of this study. Although the research is depicted as three parts, this was not a sequential process which I elaborate on in the following section. I also describe the structure of the synthesis report, or thesis, and relate the research questions accordingly to the various chapters and publications.

Research question:
How can ecodesign be cultivated in a way that incorporates both formal procedures and social practices?

Business objectives:
- Comply with the mandatory corporate standard by implementing an ecodesign procedure and tools.
- Develop product related documentation to satisfy customer demands and to anticipate future ones.
- Improve knowledge about the products' environmental impacts and life cycle thinking.

Part 1

Conceptual aim:
Analyse empirical literature on ecodesign and communities of practice

Sub-research questions:
- What is the state-of-art in ecodesign practice?
- How can the conceptual principles of communities of practice support ecodesign?

Conceptual understanding of ecodesign and communities of practice (state of the art)

Part 2

Contextual aim:
Explore social practices and formal procedures at SWP in relation to environment and product development

Sub-research questions:
- How are the company's environmental and product development practices characterized?
- What is the emphasis on formal procedures compared to social practices?

Contextual understanding of the company's environmental and product development practices

Part 3

Ecodesign solutions:
Iteratively develop, integrate, evaluate and refine ecodesign practices

Sub-research questions:
- How has ecodesign evolved in relation to formal procedures and social practices?
- How have the company's business objectives been met?

Ecodesign formal structures and social practices in accordance to SWP's business objectives

FIGURE 1-2. RESEARCH AIM AND QUESTIONS DIVIDED INTO THREE PARTS

1.2. THESIS STRUCTURE

My research is presented as a collection of published journal articles and manuscripts which are supplemented by this thesis. As shown in Figure 1-3 the thesis consists of three parts and eleven chapters that were managed iteratively rather than sequentially. It has been organized in accordance to my research strategy, which is described in section 2.2.2.

INTRODUCTION

1 Introduction

Part 1

CONCEPTUAL FRAME

2 Methodology

3 State-of-the-art: cultivating ecodesign

4 Ecodesign drivers and barriers

Part 2

CONTEXTUAL FRAME

5 Growing with the wind: a company narrative

6 Stakeholders in product development

Part 3

ECODESGIN SOLUTIONS

7 Ecodesign procedures

8 Brokers and boundary objects

9 Sustainable value (co)creation

10 Blade recycling: experiences, challenges and possibilities

CONCLUSION

11 Reflections and future directions

FIGURE 1-3. THESIS SRUCTURE DIVIDED BY THREE PARTS, FIVE SECTIONS AND TWELVE CHAPTERS

INTRODUCTION contains Chapter 1, which briefly introduces the reader to the broader problem and background of the study. It delimits the research by defining a practice based problem related to the implementation of ecodesign at the case company, SWP. The project scope, business objectives, research questions and structure of the thesis are also described.

CONCEPTUAL FRAME is composed of four chapters that constitute the first part. The methodology is represented in Chapter 2. It positions the research within the philosophy of science (pragmatism) and describes the overall research design (design-based research) that was used to explore ecodesign implementation. These elements influenced the selection of methods. The chapter concludes by describing the methodological limitations. The remaining chapters represent the state-of-the-art and seek to answer the sub-questions in Part 1. Chapter 3 has a two-fold purpose. First, it provides an in depth description of the challenges related to sustainable development at the macro-level and illustrated a number of sustainability strategies used by companies at the micro-level. Second, it gives a state-of-the-art in ecodesign and Étienne Wenger's (1998) communities of practice theory based on situated learning. Chapter 4 represents a first article that explores the drivers and barriers to ecodesign as well as the current state of implementation.

CONTEXTUAL FRAME comprises two chapters and represents the second part. Jointly, the chapters serve as a foundation for understanding the context of implementation at the case company and seek to answer the sub-questions in Part 2. Chapter 5 offers an analysis of the wind industry in which the company operates for additional context into understanding the company's strategies and practices. Similarly, it analyses the organizational setup, strategies and practices related to environmental management as well as those related to product development. Activities in Siemens AG and the Wind Power Division are contrasted. Chapter 6 encompasses the second article. It illustrates the product development activities in greater detail and assesses the degree of life cycle thinking and stakeholder participation based on a series of interviews and document analyses.

ECODESIGN SOLUTIONS includes four chapters that represent the third part and the core of my empirical research and company contributions. The chapters herein seek to answer the sub-questions in Part 3. Chapter 7 is the third article that presents a framework for ecodesign that I developed and implemented in the early part of the PhD. It is primarily based on content analysis and workshops and describes in great detail the various iterations that occurred between 2011 and 2014. Chapter 8 is the fourth article that assesses the value of the "soft" structures within companies using SWP and an additional case company. The role of environmental brokers and boundary objects are analysed in relation to the integration of ecodesign. Chapter 9 is the fifth article and concerns the external stakeholders' environmental expectations and is based on a series of interviews with customers and sales employees. It uses sustainability communication and stakeholder management theories to emphasize

SWP's role in "shaking" its stakeholders into collaborative partnerships. Similarly, Chapter 10 represents the sixth article, which is about the management of composite waste from blades at the end of their useful life cycle and how companies can embrace extended producer responsibility by engaging in industry based networks.

CONCLUSION consists of Chapter 11 which revisits the central findings from the manuscripts and publications to answer the research questions. It concludes the thesis by suggesting themes for future research and company recommendations.

PART 1
CONCEPTUAL FRAME

2 METHODOLOGY

Buchanan & Bryman (2007) inform that methodological choices are not only shaped by research aims and philosophical underpinnings but also by a combination of organizational, historical, political, ethical, evidential and personal factors. In my research, explicit business objectives and other organizational factors had a large influence on my choice of research questions and methods (cf. 1.1.2). In this chapter, I explain the research design and methods that I applied throughout my research and how some of these factors influenced my choices.

In section 2.1 I expand on the research scope and aims by describing the project characteristics in more detail. Since the business objectives were described in the former chapter, I use this section to elaborate on the project characteristics in more detail, my explicit role and location in the company which influenced my access to information, as well as synergies with other networks and students' research projects.

In section 2.2 the overall research process is presented using Saunders et al. (2009) onion metaphor. I begin by introducing the pragmatic research paradigm as it serves as the foundation for my analysis. A design-based research strategy is then presented which seeks to guide readers in understanding how my research was undertaken. In the latter part of the section my focus shifts to the applied methods as they relate to the research strategy and I finalize the chapter with a discussion about the research quality, generalizability of the findings as well as methodological limitations.

2.1. PROJECT CHARACTERISTICS

As previously described (cf. Chapter 1) the company, research problem and research scope were already delineated to a large extent meaning there was no rationale for company selection. Regardless, I provide a number of reasons supporting why SWP is an exemplary case company:

- SWP ranks amongst the ten largest wind energy technology and service providers globally so its size and market share provide a dynamic, multi-stakeholder environment (BTM 2015; Make Consulting 2015).
- The company has a broad scope of activities which encompass a wind turbines full life cycle e.g. planning, designing, manufacturing, installing, servicing and decommissioning so multiple operational areas can be assessed.
- LCA literature reveals design and manufacturing activities significantly contribute to a wind turbine's environmental impacts and there are a variety of environmental improvement potentials despite "green" product claims (Aso & Cheung 2015; Siemens Wind Power 2015).

- The company has an established history of environmental activities that are complimentary to the aims of this project (Holst et al. 2011; Rohrmus et al. 2011; Siemens 2017b).
- The company is a representative or typical case company (Bryman 2012). It is a multinational conglomerate with a matrix organizational structure where employees routinely work with colleagues from various functions, business units, locations and cultures. It exhibits similarities to other conglomerates such as General Electric and Royal Philips (Stevels 2009; 2016). Thus, research findings are possibly relevant for, and applicable to, other large companies.

This research has a longitudinal timeframe (Bryman 2012) because my employment and research at SWP began in spring 2011 and continues to date. It thereby involved repeated observations and iterative interventions on the same variables i.e. environmental and product development practices over an extended period of time. The collection of published journal articles and manuscripts were compiled between 2011 and 2017, while the thesis was written in 2017 and takes a somewhat retrospective approach to the synthesis of findings. This is particularly relevant to the research questions as I investigate how ecodesign is integrated over time within a specific contextual setting. As integration requires changes to both formal procedures and social practices i.e. company processes and employee practices, the longitudinal perspective was an essential feature in this study.

2.1.1. UNIVERSITY-INDUSTRY COLLABORATION

Dentoni & Bitzer (2015) analyse the role of universities in dealing with "wicked problems" through multi-stakeholder initiatives. They acknowledge that conventional research approaches are not able to capture the dynamic nature of sustainability challenges, and conclude by stressing a shift towards interdisciplinary collaborations between researchers and practitioners and a co-production of knowledge (p.70). In this regard, they highlight the role of researchers as knowledge experts, agenda-setting advisors and facilitators.

Working with outside partners such as universities and research institutes is a component of Siemens' innovation strategy (Siemens 2017a). Collaborative projects are aligned with Siemens' corporate strategy and core interests. Chief Technology Officer of Siemens AG, Siegfried Russwurm states:

> *"Our university partnerships give us a way to work on the technological solutions of the future with young people who are hungry for knowledge"* (Siemens 2016a).

UK Managing Director for SWP, Christoph Ehlers also states:

> *"Partnerships like this are essential to maintain our leading position in producing more efficient and reliable wind turbine technologies. Our constant dialogue with the University's experts will translate into real world solutions with benefits to both the wind industry and the environment"* (The University of Sheffield 2016).

This latter quote explicitly emphasizes the importance of university-industry collaborations for sustainable development advancements.

SWP and Aalborg University have an established history of working closely together and have been collaborating on similar topics for several years prior to the onset of this PhD e.g. in the Network for Sustainable Business Development in Aalborg. Furthermore, my university supervisor, Professor Arne Remmen and former company supervisor, EHS Specialist Tine H. Jørgensen were colleagues previously at Aalborg University and have co-authored on the topics of environmental management systems and life cycle management (Holgaard et al. 2007a; 2007b).

2.1.2. INFORMATION ACCESS

The project was initially positioned within the Supply Chain Management unit in the Global Blades Quality Management and Environment, Health and Safety (QM&EHS) department in Aalborg. Here the blade components are designed, manufactured and tested. The facility carries out new blade or blade revision projects annually, which provided a number of opportunities for participation throughout the multi-year project. Halfway through the PhD study (2014), my position and project was moved to the Division QM&EHS department in Vejle. The scope of my research and tasks then broadened from a turbine component to the entire life cycle of a wind turbine and wind farm development.

For the duration of the research, most of my time was spent at the company and to a lesser extent participating in courses and conferences. I was treated like a regular employee and granted full access to company information. I had the opportunity to interact and collaborate with colleagues from a variety of functions at all hierarchical levels within SWP e.g. designers, engineers, project managers, buyers, strategists, salesmen, other EHS specialists in environment, ergonomics, chemistry and health and safety at either functional or managerial levels. From this insider position, I was exposed to real problems that helped develop my understanding of how organizational changes and practices emerge over time, and also provided to a deeper knowledge of the contextual aspects. By studying *in* a company within its usual setting rather than just *on* a company, I was able to gain a deeper understanding of the characteristics and complexities of the complete phenomenon I was studying (Karlsson 2009).

Furthermore, I spent three months in the Energy Sector of Siemens. At that time, it was one of four sectors operating between the corporate and Division units and consisted of other energy-related Divisions i.e. Wind Power and Renewables, Oil and Gas, Fossil Power Generation, Energy Service, and Power Transmission. It has since been dissolved but at that time, I was positioned in the equivalent QM&EHS function in Erlangen, Germany. My task was to develop a boarder ecodesign procedure for all energy Divisions which was to be piloted in the Fossil Power Generation Division.

I also participated in a number of networks during the duration of my research and continue to do so. Firstly, I participate in a centre of competence for product related environmental protection which is led by the Corporate EHS function in Siemens. Here, I converse with similar colleagues from other Divisions for best practice exchange around LCA and ecodesign topics. Secondly, I represent SWP in WindEurope's sustainability task force, where I regularly meet with a number of customers, suppliers and competitors to address, from an industry perspective, different challenges related to sustainability e.g. supply chain sustainability, composite blade waste and other circular economy topics. Thirdly, I represent SWP in a Danish industrial network for LCA, ecodesign and circular economy topics. Companies include amongst others LEGO, Grundfos, Novo Nordisk, Arla, Velux and Coloplast. Participation in these networks has positively contributed to my research both in terms of bringing knowledge back into SWP as well as disseminating some of my research findings in the various networks.

2.1.3. ACADEMIC SYNERGIES

A PhD study is not an isolated experience. There are a number of possibilities to interact and collaborate with other graduate students and researchers. Although not initially intended, two additional Industrial PhD projects emerged and became interlinked with my research during the project timeframe. Additionally, three master's projects contributed to my work. A consolidated list of these interlinked projects is provided in Table 2-1 and explained below.

TABLE 2-1. SUMMARY OF GRADUATE PROJECTS THAT INTERLINKED WITH MY RESEARCH

Project title & scope	Student(s)	Year	University
Application of LCA to the wind turbine industry - a cradle-to-gate study of a wind blade; Performing a life cycle assessment of a 49 metre blade; Master's thesis	N. Swamy	2011	Aalborg University
On the shoulders of giants - life cycle based ecodesign applied in wind energy technologies; Investigating the environmental impact of four SWP wind turbines using full-scale LCA; Industrial PhD	A. Bonou	2012-2016	Danish Technological University
Recovering critical materials in wind turbines; Researching how SWP increases the resource efficiency of, and the end-of-life options for, critical materials; Master's thesis	J. Jensen	2014	Aalborg University
Design for Sustainability - Closing the Material Loops; Assessing potential circular economy applications in SWP; Industrial PhD	J. Jensen	2014-2017	Aalborg University
B2B engagement for sustainable value (co)creation; Exploring customers' environmental communication needs; Semester project	G. Jones S. Williams S. Burnette S. Levine	2016	Bard College

Representing the first synergy, Swamy's (2012) master's project interlinked in the first year of my project. Her thesis concerned the LCA of a blade and together we investigated the formalities around the data collection, impact assessment and analysis of results. This was my first time using LCA methodologies in an applied setting. No publications resulted but a slide set was created that was used to present preliminary findings to the engineers and initiate internal discussions around the impacts and environmental improvements of product components.

Bonou's (2016) project overlapped at the beginning-to-mid of my project and concerned the application of LCA methodologies to assess the environmental impact of SWP's wind turbines. Together we investigated both the formal procedures and social practices of ecodesign. Although Alexandra conducted the full-scale LCA modelling and impact assessments for four product platforms (2.3, 3.2, 4 and 6 MW turbines), I supported the LCA project team with defining the goal and scope, functional unit and data parameters and collecting data. I also assisted with the publication of four EPDs and transferring the results into the organization. We also interviewed a series of internal stakeholders on their perceptions of the product development process in relation to LCT and stakeholder participation. This collaboration resulted in a manuscript and published journal article (cf. Chapters 7 and 8 respectively).

Jensen's projects overlapped at the mid-to-end of mine and concern the application of circular economy in SWP to develop new business models and collaborations. It started as a master's thesis and became an Industrial PhD. Together we carried on from previous LCA work and co-developed a fifth LCA and EPD for our 7 MW wind turbine. We also co-supervised a group of Bard College master's students who investigated our customers environmental and sustainability requirements. This collaboration resulted in a poster for the LCM2017 conference and manuscript (cf. Chapter 9). Although Jensen was the driver of circular economy topics, I interlinked in many respects through my representations in the WindEurope and Danish industry networks (cf. 2.1.3), which resulted in another manuscript and my report for WindEurope on composite blade waste (cf. Chapter 10).

In Figure 2-1, I have depicted the two Industrial PhD projects in relation to mine using Adams et al. (2012) conceptual model to show how they address the spectrum of sustainability-oriented innovations: 1) operational optimization; 2) organizational transformation; and 3) systems building (cf. 3.2.3 for an elaborated description of the model). The academic synergies had a number of positive effects e.g. related to my research design and applied methods, interventions in the company, analysis of the findings and joint publications (cf. words on triangulation in 2.2.4).

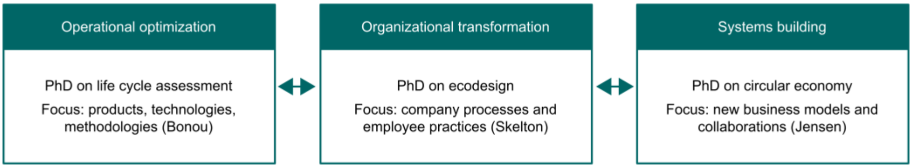

FIGURE 2-1. ACADEMIC SYNERGIES POSITIONED IN ADAMS ET AL. (2012) MODEL OF SUSTAINABLE INNOVATIONS

2.2. RESEARCH STRATEGY AND PROCESS

Saunders et al. (2009) describe the different stages in the research process using an onion metaphor where each onion layer describes a part of the research process e.g. philosophies, approaches, strategies, time horizons and methods. Decisions at the outer layers influence consecutive decisions at the inner layers so a coherent research design is established only when all of the layers are considered. Bryman (2016) accredits the onion metaphor for its usefulness and adaptability for almost any type of research. Figure 2-2 represents my research onion and my philosophical and methodological choices are described in the following sub-sections.

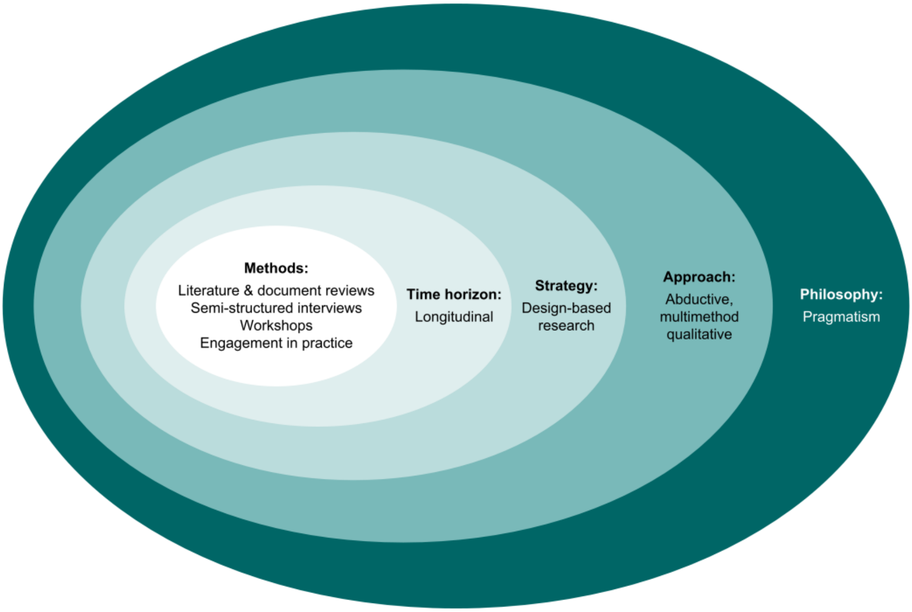

FIGURE 2-2. RESEARCH PROCESS USING THE ONION METAPHOR (SAUNDERS ET AL. 2009)

2.2.1. RESEARCH PHILOSOPHY

A research paradigm is defined by Creswell (2007) as:

> *"A basic set of beliefs that guide action"* (p.19).

While Bogdan & Biklen (1982) define it as:

> *"A loose collection of logically held together assumptions, concepts and propositions that orientates thinking and research"* (p.65).

Thus, a paradigm is not a methodology but a philosophy concerning the nature of reality that I as a researcher hold, and this reality influences the way my research is conducted and interpreted i.e. my research questions, applied methods, analysis and conclusions. For example, if I was concerned with the development and application of a specific ecodesign tool that quantitatively assessed the environmental impacts of a product my research would likely require different assumptions and positivist methods than if I was concerned with the engineers' perceptions as users of the ecodesign tool and adopted a more interpretivist approach. This project concerned integrating ecodesign and enhancing the environmental knowledge of employees to satisfy a set of pre-defined business objectives so a pragmatic approach was appropriate.

PRAGMATISIM

Pragmatism is a paradigm that centralizes real life problems which can be attributed to the fact that research typically occurs within a specific problem context whether social, historical or political (Creswell 2009). The main idea behind the pragmatic philosophy is to create knowledge from problems in the interest of change and improvement. Pragmatism is concerned not only with "what is" but also "what might be" the problems and solutions. Dewey (1931) highlights this by stating:

> *"Pragmatism [...] does not insist upon antecedent phenomena but upon consequent phenomena; not upon precedents but upon the possibilities of action. And this change in point of view is almost revolutionary in its consequences. An empiricism which is content with repeating facts already past has no place for possibility and for liberty"* (p.33).

Emphasis is given to prospective solutions, "what works" and "how", and their consequences (Creswell 2009). As pragmatism implies, solutions are thus measured in terms of their reasonableness, feasibility and usefulness and these represent the criteria for their truth, rightness and value (Ramberg 2002). Powell (2001) states:

> *"To a pragmatist, the mandate of science it not to find truth or reality, the existence of which are perpetually in dispute, but to facilitate human problem solving"* (p.884).

In this sense, truth and knowledge are what work at a given time (Creswell 2009). Pluralistic approaches are thus possible and legitimate for deriving knowledge e.g. multiple assumptions and methods can be used throughout the research process.

RESEARCH PHILOSOPHY EXPLAINED

My research is informed by a pragmatic paradigm for a two primary reasons which I discuss below. My research is:

1. Positioned within the environmental management field that is inherently pragmatic in nature;
2. Emerged from a practice based problem and set of business objectives;
3. Upheld in the relations between knowledge, human action and multiple realities.

Firstly, my research falls within the environmental discourses of organizational theory. From a broader perspective, it is concerned with understanding the relationship between companies and the environment and solving practice related problems. Prasad & Elmes (2005) inform that environmental management emerged as a prominent research field due to its pragmatic approaches in resolving contemporary environmental problems:

> *"By positioning itself in some kind of middle ground, environmental management presents itself as being a far more reasonable and practical approach for solving industrially-generated environmental problems"* (p.849).

They present three aspects to support the pragmatic claim:

1. Economic utilitarianism – going green makes economic sense.
2. Compromise – distinguishing from the ideological stances of deep ecology theories and the traditional economics of corporatism theories.
3. Stakeholder collaboration – working within a system and jointly involving all relevant actors.

Secondly and more specifically, the background for my research was derived from a set of practice related problems that were converted into research questions: *How can we understand the process of integrating ecodesign in the context of SWP? What are the drivers and barriers to ecodesign? How are existing environmental and* *product development practices characterized in the company – how can they be improved? What is the degree of life cycle thinking and stakeholder participation in product development – how can they be improved? What are the environmental impacts of SWP's products – how can they be measured and reduced? Can communities of practice support the integration of ecodesign?*

The overall aims of my research are to solve a practice related problem related to product development while exploring the value of the concept of communities of practice in an applied setting for the benefit to both the company and ecodesign discourses. I attempt to construct knowledge through a series of interventions, or ecodesign solutions. In order for my research to be valuable for SWP it must address the business objectives (cf. 1.1.1) and derive knowledge from this practice to be theoretically purposeful for environmental management and ecodesign literature (cf. 1.1.2) (Bryman & Bell 2015, p.7).

Thirdly, pragmatism goes back to Dewey's (1929) conceptualization of transactional realism which posits that the acquisition of knowledge, or the notion of reality, only reveals itself as a result of actions. This asserts that knowledge is constructed within the interplay of participants' practices and their applied setting. Biesta & Burbules (2003) explain:

> *"If one assumes, for example, that knowledge can provide us with information about reality as it "really is" and if one further assumes that there is only one reality, then one might conclude that there is eventually only one right way to act. If, on the other hand, one believes that the world of human action is created through action and interaction, and that knowledge is intimately connected with what people do, then new knowledge opens up new and unforeseen possibilities, rather than telling us the one and only possible way to act"* (p.10).

Social realities are constructed through the continual process of social interaction and sense making (Weick 1995; Saunders et al. 2009). Knowledge is a result of the participants' interactions with the technical ecodesign artefacts. Knowledge is also shaped by the interactions between researcher, practitioner and participant. It is the practical experiences working with ecodesign in organizational, historical, cultural and political contexts that give rise to new knowledge.

In my research, I also acknowledge that subjectivism is an inherent outcome of pragmatism. Knowledge emerging from interactions is individual and subjective, in which there are multiple realities. Consequently, no single point of view can give a full picture (Saunders et al. 2009). The social world can be any shape, depending on how one chooses to look at it (Gregen 1999) which Eisner (1993) calls "pluralism".

In my research there are likely to be multiple realities about the product development process. Product development occurs within a dynamic and social context whereby actors from varying functional units, and thereby "worldviews" interact simultaneously and concurrently to develop a product. Similarly, there will be diverse views about ecodesign and the proposed ecodesign solutions based on participants' different functional views and interpretations of it. I use Saxe's (1872) *The Blind Men and the Elephant* parable to illustrate these multiple realities of ecodesign. In brief, a group of blind men touch an elephant without knowing what it is. Based on individual experiences, each of the men describes the animal's characteristics but since they have touched different parts of the animal they cannot agree on what animal it is. Each blind man is trying to proclaim an absolute truth, but it is relative to experiencing only one part of the elephant. This is an effective metaphor to illustrate co-existing realities and relative knowledge that is based on subjective experiences.

I adapt this metaphor to the integration of ecodesign where there is a change the design engineer views ecodesign as a matter of increasing energy output and reducing material outputs, while the project manager views ecodesign as being not conducive to their project time plan or budget, while lastly, the key account manager sees the outcomes of ecodesign as a key feature to his sales pitch. Ecodesign practice will likely emerge differently between functional groups as a result of different interpretations and it will likely change over time and context. To better facilitate integration, I sought to understand the actors' subjective realities and their motivations and challenges in relation to ecodesign practice.

To summarize, my research does not aim for any objective, universal truth related to ecodesign integration. Rather, it contributes to practical methodologies for understanding one contextual approach to ecodesign integration. I believe that knowledge is contextual and embedded in practical experiences that are socially constructed. Knowledge is also subjective and based on multiple realities as experienced by the various stakeholders throughout my research as well as my own as both a researcher and practitioner. In respect of this, my knowledge contributions are generated through actions and experiences rather than just the outputs of my publications and thesis; they are mere documentation of some of the knowledge generated.

ONTOLOGICAL, EPISTEMOLOGICAL AND AXIOLOGICAL ORIENTATIONS

A paradigm's philosophical assumptions include a stance toward the nature of reality (ontology), how the researchers know what they know (epistemology), the role of values in the research (axiology) and the methods used in the process (methodology) (Creswell 2007). Table 2-2 represents my philosophical assumptions and how they relate to the development of knowledge and the nature of that knowledge.

TABLE 2-2. PHILOSOPHICAL ASSUMPTIONS AND IMPLICATIONS TO MY RESEARCH (ADAPTED FROM CRESSWELL 2007; SAUNDERS ET AL. 2009)

Pragmatism	Implications to my research and practice
Ontological: Researcher's view of the nature of reality	
- Constructive knowledge useful for the purpose of action and change - Multiple, social realities - Reality is what is useful, practical and workable – context dependent	- Applied, problem based research on ecodesign integration - Knowledge is contextual and embedded in practical experiences that are socially constructed - Multiple realities as seen by the various stakeholders as well as my own as both researcher and practitioner - Ecodesign solutions developed and integrated based on SWP's organizational context – preference given to participatory, simplicity, applicability, feasibility - Ecodesign solutions refined based on emergent contextual and conceptual developments as well as from stakeholders and personal experiences
Epistemological: Researcher's view of what constitutes acceptable knowledge	
- Objective facts and/or subjective meanings - Different perspectives to help interpret data - Constructed, based on explanations giving best outcomes - Value of knowledge equal to its practical use	- No single point of view can give a full picture - Multiple, subjective perceptions of the proposed ecodesign solutions captured in quotes from various internal and external stakeholders - Analysed other companies' experiences by interviewing and analysing literature from applied ecodesign studies to develop more acceptable ecodesign solutions and research findings
Axiological: Researcher's view of the role of values	
- Value laden, play a large role in interpreting results	- Subjective values emerge over time, affecting the development, integration and refinement of ecodesign solutions - Practitioner values inseparable from researcher values - highly intertwined - Interpretations often discussed with environmental colleagues and the other synergistic student projects

Methodological: Researcher's strategy and data collection methods

- Multiple method designs - Theories as metaphoric tools	- Primarily qualitative with the exception of LCA methodologies - Abductive approach using design-based research and mixed methods - Iteratively "develop", "integrate", "evaluate" and "refine" ecodesign solutions while adjusting research questions and methods - based on emergent contextual and conceptual developments as well as from stakeholder and personal experiences - Theories seen as tools to intervene rather than reveal realities

QUALITATIVE, MULTIMETHOD APPROACH USING ABDUCTIVE REASONING

This research predominantly follows a qualitative design using a variety of methods for developing, integrating and refining the ecodesign solutions. A qualitative approach supports me in understanding how participants respond to particular ecodesign solutions in their natural settings (Saunders & Tosey 2012). Thus:

> *"The basic subject matter is no longer objective data to be quantified, but meaningful relations [and practices] to be interpreted"* (Kvale 1996, p.11).

I acknowledge my use of quantitative LCA methods intermittently throughout my research as a tool to assess product environmental impacts but emphasize that my primary interests were related to the integration of LCA tools and the use of LCA impact results in the product development projects. In another sense, LCA tools and organizational procedures were perceived as boundary objects that could be used to facilitate sense making around LCT, stakeholder engagement and other ecodesign concepts. Paraphrasing Lincoln et al. (2011), qualitative research is defined as:

> *"A situated activity that locates the researcher in the world and consists of a set of interpretive practices that makes the world visible. The practices transform the world and turn it into a series of representations e.g. interviews, observations, self-memos, etc. It involves an interpretative approach to the world. Qualitative researchers study people and practices in their natural settings and try to make sense of this in terms of the meaning people bring to them*" (p.3).

Of the three possible forms of logical inference, I used abductive reasoning to construct explanations and draw conclusions in my research. Where:

> *"Deduction proves that something must be and induction shows that something actually is, abduction merely suggests that something may be"* (Peirce 1934, 5.172).

Abductive reasoning typically begins with an incomplete set of observations or empirical facts and seeks to find the most likely explanation for something using the information at hand. I describe my research methods and data analysis in later subsections (cf. 2.2.3).

2.2.2. RESEARCH STRATEGY

The research strategy equates to how a researcher intends to undertake their research and is linked to the research philosophy (Saunders et al. 2009). The aims of my research are to explore how ecodesign artefacts can be contextually developed and integrated as well as how ecodesign can be contextually understood and practiced. In this sense, focus is given to both the formal procedures (ecodesign artefacts) as well as the social practices (ecodesign knowledge and practice). I begin this subsection by describing two closely related research strategies, specifically design-based research and action research, and illustrate their complimentary and contrasting features. I then provide a detailed explanation of my overall research strategy.

DESIGN-BASED RESEARCH

Design-based research (DBR) is an emerging research strategy from the 1990s which developed primarily in response to the need for more practical theories and frameworks (Ørngreen 2015). It is commonly used by scholars from the learning as well as information systems sciences. Consequently, various terms are used to describe DBR including design science research (DSR) (Collins 1992; Holmström et al. 2009), design research (Kelly 2004; Romme 2003) and design experiments (Brown 1992; Cobb et al. 2003). There is no standard definition of DBR as authors are not aligned whether it is a research approach, strategy or method. Below are two definitions:

> *"DBR is not so much an approach as it is a series of approaches, with the intent of producing new theories, artefacts and practices that account for and potentially impact learning in naturalistic settings"* (Barab & Squire 2004, p.2).

> *"A systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real world settings, and leading to contextually-sensitive design principles and theories"* (Wang & Hannafin 2005, p.6).

DBR transpired out of the growing need to develop research that addressed practice related problems and resulted in useable knowledge. In this respect, research could be evaluated not only on the merits of academic quality but also on the application to, and impact on, practice (The Design-Based Research Collective 2003). Several authors claim DBR bridges the gap between research and practice and contributes to both the improvement of professional practice and the development of organizational theory (Romme 2003; van Aken 2004). In this regard, Bell (2004) states:

> *"It is more useful to consider DBR as a high level methodological orientation that can be employed within and across various theoretical perspectives and research traditions in order to bring design and research activities into a tight relationship in order to advance our understanding of learning-related educational phenomena"* (p.245).

In management studies however, DBR is not widely applied as a research strategy and few guidelines exist on how to utilize it (Andriessen 2008). Easterday et al. (2014) also comment on the lack of clarity with methodologic aspects as well as other constraints such as difficulties differentiating from other research strategies, particularly design as well as the limited number of studies addressing DBRs effectiveness as a strategy. Challenges with the alignment and analysis of large data-sets (Dede 2004) and researchers' difficulties remaining unbiased due to their high involvement in the research design (Barab & Squire 2004) are other critical perspectives of DBR.

ACTION RESEARCH

DBR is often compared to, and sometimes confused with, action research (AR). Similar to DBR, AR can be traced back to the early works of John Dewey, Kurt Lewin and John Collier and holds a number of synonyms including action science (Argyris et al. 1985), action oriented research (Coghlan & Coughlan 2010) and participatory (action) research (PAR) (Borda 2006; Park 2006). Many AR definitions also exist, but some suggest this is out of necessity due to the unique settings and processes applied (Noffke & Stevenson 1995). Some of these include:

> *"AR is a participatory, democratic process concerned with developing practical knowing in the pursuit of worthwhile human purposes, grounded in a participatory worldview [...]. It seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities"* (Reason & Bradbury 2006, p.1).

> *"AR may be defined as an emergent inquiry process in which applied behavioural science knowledge is integrated with existing organizational knowledge and applied to solve real organizational problems. It is simultaneously concerned with bringing about change in organizations, in developing self-help competencies in organizational members and adding to scientific knowledge. Finally, it is an evolving process that is undertaken in the spirit of collaboration and co-inquiry"* (Shani & Pasmore 1985, p.439).

Lewin (1946) associates AR to a spiral staircase of cycles, whereby each step encompasses a circle of planning, action and fact-finding about the result of an intervention. AR comparatively explores effects around change, or social action, to which is referred to as "social engineering". Collier believed the most important tool in changing practice was research so long as it was conducted as a joint effort between researcher and participants (Pasmore 2006). Several AR studies have demonstrated that participatory management methods, where employees can discuss and co-develop potential changes, are more effective than conventional change processes (Coch & French 1948; Trist 1979).

Frideres (1992) provides a critical review of AR and claims a number of controversies with the research strategy. He informs that AR has shifting definitions, lacks methodological vigour and therefore cannot be verified by others. Confusion also surrounds the research goals of AR - whether to develop new knowledge, educate the people or create action. Further, he comments on the misuse of AR by non-academics such as community development officials for political, religious and ideological means.

SIMILARITIES AND DISTINCTIONS BETWEEN DBR AND AR

Discrepancies surround whether DBR and AR have strong correlations or decisive contrasts (Goldkuhl 2013). They are similar in that they: share many epistemological, ontological, and methodological underpinnings; identify real world, practice based problems and incorporate the ”messiness" in relation to complexities, dynamics and limitations of everyday practice; subsequently apply iterative actions to improve the status quo because of their change oriented approach; and devise collaborative relations between researchers, practitioners and participants. However, they’re distinct in a number of other respects: DBR is not as established as AR; theorizing is seen as an ongoing process in DBR and continuously intersects with practical problem solving; DBR is more technologically oriented on the creation of artefacts and tends to neglect interventions to practice; and AR is rooted in situational inquiry and tends to focus on the local rather than general practices.

Several authors have begun to evaluate the value in combining DBR and AR strategies (Baskerville et al. 2009; Cole et al. 2005; Goldkuhl 2013; Lee 2007; Sein et al. 2011; Wieringa & Morali 2012), all of which are well described in Goldkuhl’s (2013) review. Sein et al. (2011) propose the action design research (ADR) strategy where DBR and AR mutually reinforce one another in a way that produces more rigorous and relevant research findings and address some of the critical perspectives previously mentioned. The central properties of each strategy are illustrated in Table 2-3.

TABLE 2-3. PROPERTIES OF ACTION RESEARCH, DESIGN-BASED RESEARCH AND ACTION DESIGN RESEARCH STRATEGIES (SEIN ET AL. 2011)

Property	DR	AR	ADR
Artefact	Central	Peripheral	Central
Organizational impact	Peripheral	Central	Central
Subject participation in research design	Possible	Mandatory	Mandatory
Subject feedback	Discrete	Continuous	Continuous
Transferability	Explicit	Implicit	Explicit
Success measure	Quantifiable measures of artefact behaviour	Organizational impact	Organizational and artefact generalizability

RESEARCH STRATEGY EXPLAINED

Due to the linkages between my research questions and SWP's business objectives (cf. Chapter 1), it was important that the strategy of inquiry I used throughout my research extended from:

> *"[...] pragmatic lines of inquiry where theories are judged not by their claims to truth, but by their ability to be applied to the real world"* (Barab & Squire 2004, p.6).

The research strategy had to be flexible and based on a series of iterative approaches and mixed methods in order to produce new artefacts and practice interventions in SWP's organizational context. At the same time it had to contribute to ecodesign literature and this was done by using a learning theory, namely communities of practice. The use of DBR and elements of AR helped me to understand the relations between artefacts, knowledge, practice interventions and theory as well as co-develop ecodesign solutions that I could analyse their effects on practice.

Hevner's three cycle DBR framework (Hevner 2007; Hevner et al. 2004) was used to explain the overall research strategy. McKenney & Reeves' (2012) generic DBR model was used to explain the evolution of ecodesign solutions in more detail. Both of these are elaborated on below. Engagement in practice at the company was inspired by AR due to the participatory elements but I do not claim to have fully adopted an ADR strategy.

Figure 2-3 represents my research strategy and helps articulate how the research was understood, executed and evaluated at a higher level. On the right side of the figure, a conceptual frame is depicted, also referred to as Part 1. It contains applicable materials and tools for carrying out the research, including:

1. Established theories and previous empirical studies in literature.
2. Methodologies.
3. Personal knowledge and capabilities.

Ecodesign and organizational studies from secondary sources provide reference frameworks, tools and best practices for me to consider in the development and integration stages of the ecodesign solutions. While the theories and methodologies help me to evaluate and refine the outcomes of my research.

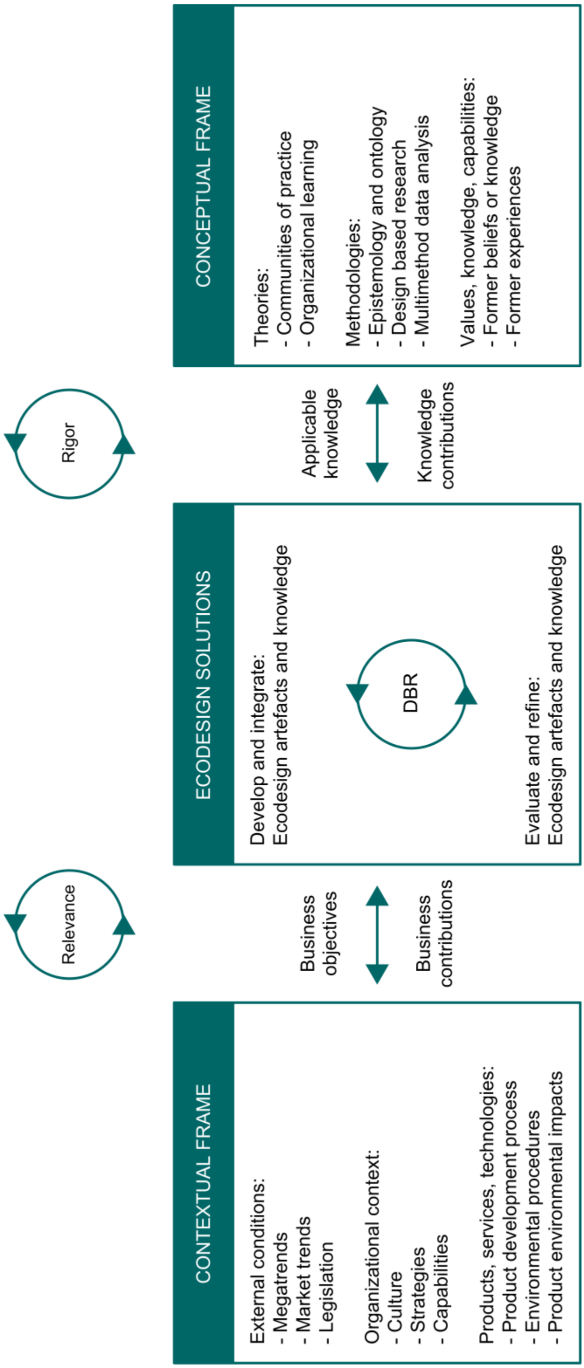

FIGURE 2-3. RESEARCH STRATEGY (INSPIRED BY HEVNER ET AL. 2004; HEVNER 2007)

A contextual frame is depicted on the left side of the figure and also referred to as Part 2. It represents the environment and problem space for the company and includes three elements: 1) external conditions e.g. current megatrends, industry activities, legislation and market mechanisms; 2) an organizational context e.g. existing structures, strategies, culture, drivers, barriers, employee characteristics; and 3) characteristics of the products, services and technologies. By understanding these I am able to contribute to the company's business objectives and knowledge gaps in ecodesign literature.

The empirical research is positioned in the centre of the model in which a number of ecodesign artefacts were created and a number of ecodesign practices emerged, which I refer to as ecodesign solutions. I also refer to this part of the diagram as Part 3. Artefacts denote the tools and processes in SWP which I, in my practitioner role, contributed to developing and integrating while practices denote the emergent way of doing things. Artefacts were not only created, but also evaluated and refined using iterative and participatory approaches.

Alignment with both the contextual and conceptual frames is important as Hevner (2007) claims:

> *"DBR is essentially pragmatic in nature due to its emphasis on relevance; making a clear contribution into the application environment. However, practical utility alone does not define good DBR. It is the synergy between relevance and rigor and the contributions along both the relevance cycle and the rigor cycle that define good DBR"* (p.91).

Relevance is achieved by incorporating the contextual factors e.g. business needs, external trends, product characteristics, when developing and evaluating the ecodesign solutions. Rigor is also achieved by applying existing theories and methodologies appropriately from the conceptual frame. Figure 2-5 depicts the thesis chapters in relation to the DBR model.

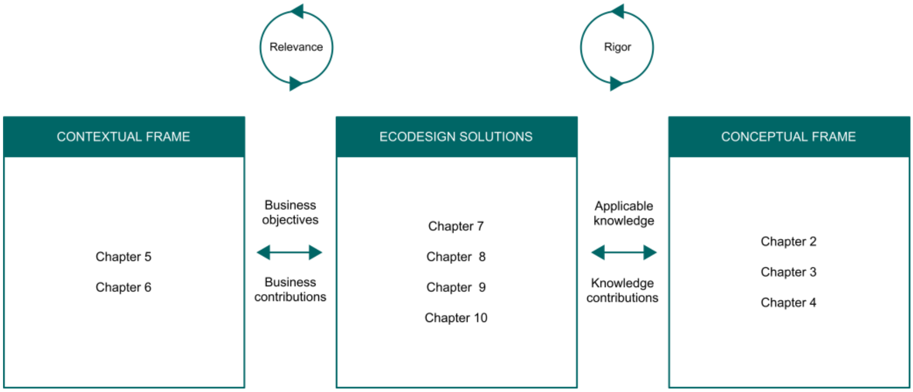

FIGURE 2-4. CHAPTER CONTRIBUTIONS IN RELATION TO THE RESEARCH STRATEGY

RESEARCH PROCESS EXPLAINED

The central pillar (Part 3) of the research strategy is shown in Figure 2-6. McKenney & Reeves (2012) generic model for design research (GMDR) is used to describe the evolution and emergence of the ecodesign solutions over the project timeframe. The upper part of the figure is the GMDR showing an integrated cycle of research and design activities, which was developed based on a synthesis of former approaches. Three shapes represent different concepts related to the model:

- Square for the three phases of research and development activities (analysis/exploration, develop/integrate, evaluate/refine).
- Rectangles for the two main outputs of design research (maturing intervention and theoretical understanding).
- Triangle for the interactions with practice as an increasing phenomenon over time (implementation and spread).

The lower part of the figure is a representation of my research strategy. On the left I provide a timeframe of the project. My research is characterised by a longitudinal timeframe, in comparison to a cross-sectional timeframe. Over an extended period of time (2011-2017), I gained insights into the norms, values and behaviour patterns related to environmental and product development activities at SWP. I was also able to experience and analyse changes to organizational structures and artefacts as well as social practices. For example, changes to SWP's organizational charts and product portfolios occurred in response to industry and market changes as well as a general maturation in the company which thereby had implications on the artefacts and practices. The boxes indicate the methods, the outcomes and how they contribute Parts 1 and 2 of the research strategy.

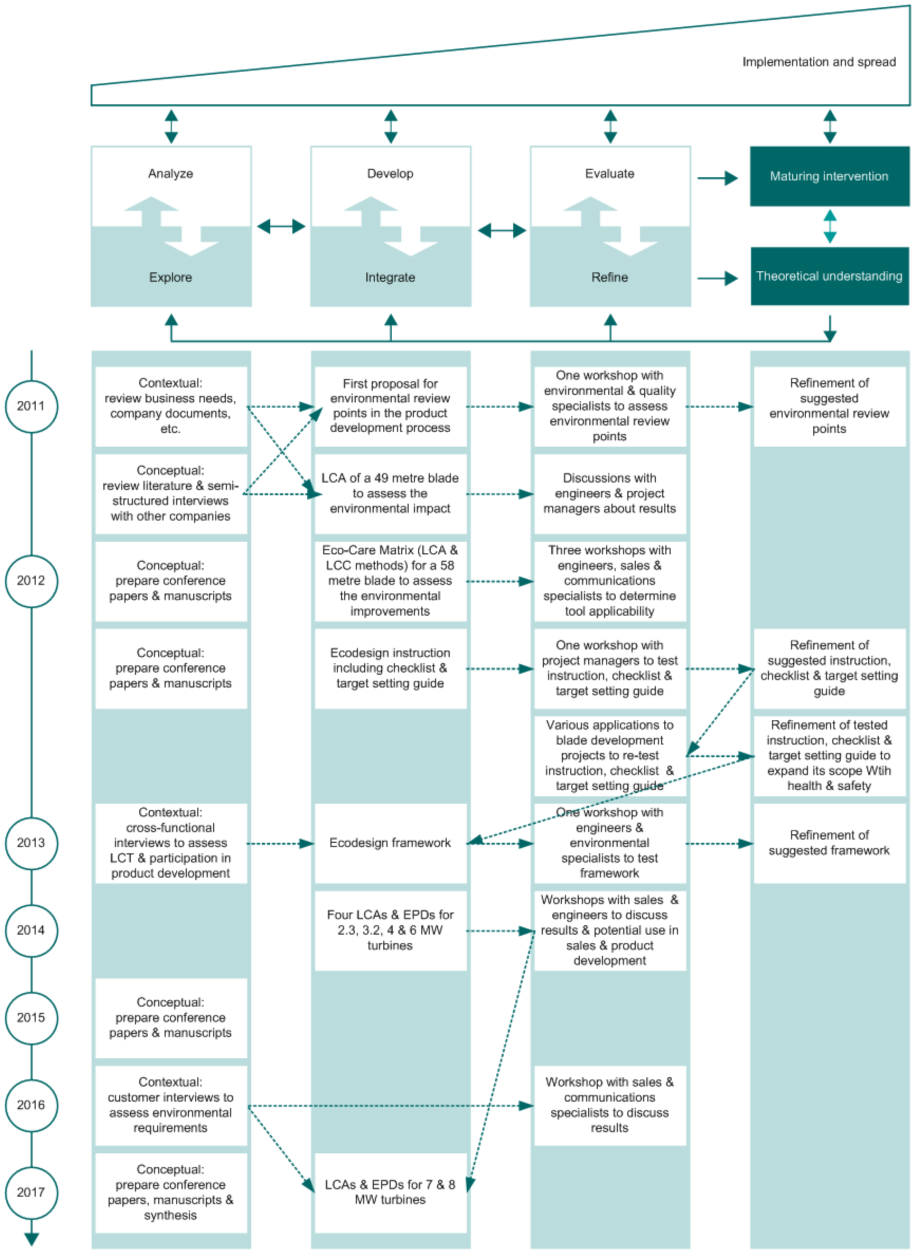

FIGURE 2-5. RESEARCH PROCESS WITH TIMEFRAME AND ECODESIGN SOLUTIONS (ADAPTED FROM MCKENNEY & REEVES 2012)

Throughout this extensive time I was able to witness, analyse and explore a number of exciting advancements which influenced both the contextual and conceptual frames of my research. Some of these included:

- Innovations in the product portfolio, particularly turbine size increases (from 2 to 8 MW) and growth in the offshore wind market, including lower cost of energy and advancements in floating turbines.
- Perpetual organizational changes affecting internal processes, department structures and even my own position, and thereby scope, within the company.
- Trends in the sustainability discourse where literature shifted from ecodesign to circular economy topics.
- Adaptations in opinions of, and practices related to, product development and sustainability topics.
- My own maturation as both an early academic and young professional.

Preliminary literature and document reviews as well as interviews helped me in the first phase to understand the current state and business needs, as well as to identify potentially relevant approaches and interventions. This information was then used to develop and integrate appropriate ecodesign solutions in the second phase. Initial interventions were simple and gradually expanded over time as a result of ongoing instances of evaluation and refinement with participants. Workshops and meetings were useful modes to communicate around the proposed solutions. Chapter 7 provides a more detailed account on the iterations used to develop the ecodesign procedure.

Bryman (2012) acknowledges the “messiness” of business research and the importance of researchers to remain flexible to avoid imposing an inappropriate frame of reference in the company. Research plans must be adaptable in response to problems and opportunities that arise throughout the process. My research questions and work packages had been largely defined from the onset of the project. However, the design and construction of artefacts became iterative in nature in response to contextual and conceptual changes as previously described. For example, at the end of 2013 when the ecodesign procedure had been developed, I had the intention of following a specific development project with a wider scope than previous projects – it was for a whole turbine upgrade rather than just a rotor blade. I was anticipating to be closely linked to the project, as I had been with previous projects, but the design had already progressed to a point where I would have had to retroactively work with the project and my framework. This would have been ok but this issue was compounded with geographical and organizational constraints e.g. knowing the right people. During that same time, we were starting to define the scope and collect data for the four LCAs that followed in 2014, so this gradually became the primary focus.

REFLECTIONS ON RESEARCHER-PRACTITIONER ROLE

The dual role as researcher and practitioner is explained in Table 2-4. The Design-Based Research Collective (2003) refers to this as *"the dual intellectual role of advocate and critic"* (p.7) where emphasis is placed on the tensions between "rigour" and "relevance". Using three aspects important to both research and practice, I describe how both foci of interest must be satisfied, how I was governed by two sets of prerequisites, and how my work should be measured as two different outcomes.

My research was designed in a way that I was able to satisfy both orientations. There was a significant overlap in the foci of interest because the research questions were developed based on the explicated business objectives (cf. Chapter 1).

TABLE 2-4. RESEARCHER AND PRACTITIONER ORIENTATIONS (ADAPTED FROM SAUNDERS 2011)

	Researcher	Practitioner
Focus	Basic understanding	Useable knowledge
	General enlightenment	Instrumental
	Theoretical explanations to problems	Practical solutions to problems
	"Why" knowledge	"How to" knowledge
	Substantive theory building	Local theory-in-use
	Scientifically credible output	Practically useful guidance
Prerequisite	Theoretical and methodological rigor	Business value and timeliness
Outcome(s)	Academic publications in reviewed journals	Practical outcomes and practice implications

2.2.3. RESEARCH METHODS

The research strategy provided a framework for the collection and analysis of data (Bryman & Bell 2015). Data collection was guided through the use of four qualitative methods and one quantitative method: engaging in practice, literature reviews and document analyses, semi-structured interviews, workshops, and LCA methodologies. Figure 2-7 depicts the methods according to when each was used.

FIGURE 2-6. DATA COLLECTION AND ANALYSIS METHODS IN RELATION TO PROJECT TIMEFRAME

The methods are depicted in Table 2-5 in relation to the articles and a brief description of each follows below. Additional methodological details can be found in the respective chapters.

TABLE 2-5. METHODS USED IN THE ACADEMIC ARTICLES

Methods	Chapters representing articles					
Chapters	*4*	*6*	*7*	*8*	*9*	*10*
Engaging in practice	•	•	•	•	•	•
Literature reviews, document analyses	•	•	•	•	•	•
Semi-structured interviews	•	•	•		•	
Workshops			•			
LCAs			•			

ENGAGING IN PRACTICE

Due to the length and embedded nature of this industrial PhD, I was continuously observing, participating and intervening in the daily practices and routines. Bryman (2012) informs that unstructured observations are a method to assess the practices and culture with the aim of developing a narrative of those practices. Based on this, emphasis is placed on the evolution of the contextual frame and company practices in my thesis.

Meetings, conferences, trainings and networks were common modes to which I could gather information. I had the opportunity to interact and collaborate with colleagues from a range of functions at all hierarchical levels. I also engaged with customers, competitors, waste handlers, suppliers and professionals from other ecodesigning companies through my participation in networks (cf. 2.1.2). Although I did not record specific practice observations, I did maintain a set of notes and frequently wrote interesting quotes I overheard engineers and project managers saying in relation to environment or product development. Data analysis was further supported by minutes of meetings and email correspondence.

LITERATURE REVIEWS AND DOCUMENT ANALYSES

In addition to engaging in practice, I relied heavily on literature reviews and document analyses iteratively throughout my research. Initial literature reviews and document analyses set directions for additional reviews and analyses. Literature reviews were needed from the study's onset in order to determine the state-of-the-art in both empirical ecodesign studies and communities of practice theory. This contributed as inputs to the development and integration of the ecodesign solutions. The academic articles involved some form of literature review. However two extensive reviews were produced in two articles: reviews were used in Chapter 4 around the drivers and barriers of ecodesign as well as the soft side of ecodesign and communities of practice and Chapter 10 around the state-of-the-art in the management of composite blade waste.

Document analysis concerned company processes which took the form of written and pictorial text, as well as company procedures, policies, minutes of meetings, email communications, project reports, presentations, quarterly and annual reports, internal and external websites, etc. Content related to product design was the primary focus as this was a new subject for me, was context specific and needed to be understood before proposing interventions. The product development process was being revised at the onset of my study and had extensive documentation attached to it. It was interesting to see the pictorial representations of the product development processes and compare them to how things actually were in practice. Siemens is a very process-oriented company so many of the processes and procedures clearly defined the relevant functional stakeholders and the scope of their roles. This contributed to the design and evaluation of the ecodesign solutions as well as to my publication in Chapter 7 on the ecodesign procedure.

Data analysis was supported by thematic groupings from literature reviews and gap analyses in document reviews. The company-specific content was assessed to ensure validity using Scott's (1990) criteria: authenticity, credibility, representativeness, and meaning. Since the material was classified as official and originates from a legitimate origin, it was assumed to be authentic, meaningful and representative to the company's operations. However, the material representativeness may be moderately affected a number of organizational changes and process revisions. Company material is deemed credible because it undergoes an internal review process before publication.

SEMI-STRUCTURED INTERVIEWS

A total of 46 semi-structured interviews were conducted. There were three series of interviews, all of which were exploratory in nature with the overall goal to uncover tacit knowledge that was embedded in practices, and not explicitly depicted in company documents. An overview of the respondents and the scope of their questions are provided in Table 2-6. The interviews contributed to the majority of manuscripts and publications, with the exception of Chapter 11.

TABLE 2-6. SEMI-STRUCTURED INTERVIEWS INCLUDING RESPONDENTS, SCOPE AND MODE

Date	Respondents	Scope of questions	Mode
2011	Environmental, sustainability or R&D professionals, including managers from seven European multinational companies	Context of the companies' operations and their ecodesign practices, including drivers, barriers and countermeasures for overcoming the identified challenges	Five virtually and two face-to-face
2013	SWP employees and managers from technology, marketing, project management, design and engineering, procurement, quality and EHS functions	Operational challenges around the Innovation focus and product development process; perceived degree of stakeholder involvement in product development; understanding of LCT	Fourteen face-to-face
2016	SWP employees from, sales and marketing, sustainability, EHS and strategy functions as well as professionals from seven key customers	How sustainability activities are currently communicated to customers and the importance of such activities for the customer during the tender phase	Twenty five virtually

Respondents represented both internal and external stakeholders and different hierarchical levels including managers as well as corporate, global and local functions. Respondents were selected through one of two means: they were either recommended by colleagues or were identified and selected using a "judgmental" sampling strategy, (also referred to as "purposive" or "subjective" sampling). Battaglia (2008) inform that this non-probability form of sampling selects a representative sample based on an expert assessment of the respondents' abilities to provide comprehensive information, rather than basing it on a statistical determinant.

Interview guidelines were prepared to direct the discussions. The semi-structured format allowed a large degree of flexibility that enabled follow up questions, clarifications or elaborations on different aspects. In the series of interviews conducted in 2013, conceptual diagrams for the product development process as well as conceptual models of LCT were used as boundary objects with the respondents. An exercise to map the stakeholders in the process was also used and a rating scale of how respondents perceived the innovation process (cf. Chapter 6). All interviews were an average length of one hour and were recorded and transcribed in various degrees of detail for further analysis. Data analysis was supported by transcriptions and thematic groupings of responses.

WORKSHOPS

Workshops were proposed as effective tools in McAloone & Bey's (2009) seven step ecodesign guide. Myrdal (2010) created a workshop approach to support organisational learning, collaboration, and commitment related to ecodesign in her doctoral thesis. She categorized four types of workshops: consequence assessment, strategic, creativity and tool based workshops. Each of these are described in Table 2-7 and are used to characterize the type of workshops used in this research.

TABLE 2-7. FOUR TYPES OF ECODESIGN WORKSHOPS (SUMMARIZED FROM MYRDAL 2010)

Workshop type	Awareness and motivation	Ecodesign management	Social network
Consequence assessment	Knowledge about materials' and products' environmental impacts	Environmental impact assessment of materials and products and improvements via ecodesign strategies	Determine relevant product related actors and involve those connected to the life cycle stages
Strategic	Knowledge about company and product strategies	Align product specific ecodesign goals with company and product targets	Involve employees in developing company and product strategies
Creativity	Create common understanding about product/service innovation	Develop more environmentally friendly alternatives	Develop new practices for cooperation for collaborative idea generation
Tool	Provide overview of available tools and their purposes	Introduce, select, and develop tools to be used in the other workshops	Involve employees in developing and use of tools giving special attention to competences

Seven workshops were conducted over the project duration with an overall goal to gather feedback for the evaluation and refinement stage of the research. The durations varied from one hour to a full day. An overview of the participants and scope of the workshops are provided in Table 2-8.

From my experiences, workshops require extensive amounts of preparatory work compared to other methodologies. They can last numerous hours where the researcher might also have to facilitate and keep the participants engaged. Conversely, one effective workshop can replace several individual interviews. They also provide an additional dynamic due to the multiple participants, particularly if these participants are from different functional departments. This can help to generate a wider (360 degree) picture around a concept or problem where the participant views can be assimilated or contrasted against one another. I perceive the communities of practice theory as especially valuable for workshop methodologies, where participants can express their opinions and concerns while reinforcing one another in a social network format. It is supportive of the sense making process where participants can co-develop a mutual understanding around a specific concept. These methods can also serve as indirect trainings, creating awareness, reinforcing the importance of environmental topics and motivating the participants towards ecodesign.

TABLE 2-8. WORKSHOPS INCLUDING PARTICIPANTS AND SCOPE

Date	Participants	Workshop scope	My role
2011	Twenty SWP employees from EHS and quality functions	Workshop: strategic or tool, full day Specify environmental review points in gates and milestones of the product development process	Participant
2012	Twenty four SWP employees from EHS, sales, marketing, communication, project managers and design engineering functions	Three workshops: tool or consequence assessment, one hour each Determine the applicability of the Eco-Care Matrix in marketing and engineering practices	Facilitator
2013	Thirteen SWP employees from project management and EHS functions	Workshop: strategic or tool, half day Gather feedback and test the instruction, checklist and target setting guide	Facilitator
2013	Seven SWP employees from EHS and design engineering functions	Workshop: strategic or tool, half day Gather feedback as input to the ecodesign procedure	Facilitator
2016	Twenty three SWP employees from sales, marketing and communications functions	Workshop: strategic, creativity or tool, two hours Present findings and gather feedback for next steps of environmental communication and sales materials Two hours	Facilitator

LIFE CYCLE ASSESSMENTS

LCAs were the only quantitative method used intermittently throughout my research. As I previously described however (cf. 2.2.1), my primary interests were related to the integration of LCA tools and the use of LCA impact results in the product development projects. I provide a brief overview of the LCA studies that I participated in during the research timeframe in Table 2-9. My role was related to all aspects except the modelling, including:

- Setting the goal and scope and system boundaries.
- Collecting data.
- Interpreting the results.
- Preparing EPDs and other communication material.
- Disseminating the results in workshops or product development projects.

A more in-depth description of the technical methods can be found in the publications listed in the table below e.g. goal and scope, system boundaries, data collection and modelling assumptions, etc.

TABLE 2-9. LCAS CONDUCTED THROUGHOUT PROJECT TIMEFRAME

Date	Scope	Publications
2011	Cradle-to-gate LCA for 49 metre blade	Swamy (2012)
2012	Eco-Care Matrix, LCA and LCC methods for 58 metre blade	Internal report
2014	Full scale LCAs for four turbines (2.3, 3.2, 4 and 6 MW)	Published EPDs, Bonou et al. (2016), Bonou (2016); Bonou et al. (2015); Siemens Wind Power (2015)
2016	Business case of LCA methodologies for resource optimization and risk reduction	Internal report
2016	Full scale LCA for 7 MW turbine	Published EPDs (Siemens Wind Power 2017a)

2.2.4. RESEARCH QUALITY AND LIMITATIONS

Three of the most common criteria for measuring the quality of organizational research are replication, reliability and validity (Bryman & Bell 2015). Replication is closely related to reliability but more concerned with the repeatability of results. Replication in qualitative, business research is not so common since the contextual underpinnings have a significant influence on the methods applied and the result obtained. It is also not possible to replicate a social setting and the circumstances surrounding it. However, some elements of a study can be replicated or adapted to the specific needs of future studies.

Reliability concerns whether or not the research findings are consistent and dependable. Reliability was ensured by following a structured and transparent DBR research strategy that was formulated in an iterative way to meet the needs of the business and the rigor of the knowledge base. The strategy can also be reproduced for other projects with similar organizational contexts and tweaked to the needs of those organizations. Interview transcripts remain confidential due to corporate confidentiality restrictions but can be referred to on specific requests.

Validity concerns the integrity of the findings. *Ecological validity* concerns internal validity or the search for data in naturally occurring environment contexts and situations. It is somewhat inherent in this research because the contextual environment was a significant element of the DBR strategy. This ensured that the ecodesign solutions produced were both technically valid and socially aligned to the organization's needs. *External validity* concerns transferability and is a factor in this research because the findings should illicit some degree of generalizability for other organizations seeking to implement ecodesign.

Triangulation is a technique that can be used to enhance the validity of findings. It is:

> *"A method of cross-checking data from multiple sources to search for regularities in the research data"* (O'Donoghue & Punch 2003, p.78).

Denzin (1978) identified four types of triangulation: 1) theory triangulation; 2) data source triangulation; 3) investigator triangulation; and 4) method triangulation. The latter three of these were applied in this research:

1. Data source triangulation involves the collection of data from different times, spaces and people: by researching over a longitudinal time frame, at two levels of the product development organization and based on different participants inside and outside the organization (cf. 2.1).
2. Investigator triangulation involves participation with multiple researchers: by researching in parallel with two different Industrial PhD students to encourage multiple observations and confirm conclusions (cf. 2.1.3).
3. Method triangulation involves the use of multiple techniques: by using different methods to collect data (cf. 2.2.3).

3 STATE-OF-THE-ART: CULTIVATING ECODESIGN

In this Chapter, I provide a background to support my research on ecodesign. I begin by framing the wider research problem at the macro level and then introduce the state-of-the-art for ecodesign by positioning it within Wenger's (1998) Communities of Practice theory.

In section 3.1 I introduce the broader context of the research problem by describing modern challenges to sustainable development. More specifically, I describe the environmental implications of megatrends such as climate change and resource scarcity. This is followed by a description of the five waves of environmental activism that evolved at the macro level in response to the megatrends. In order to understand the sustainability imperative I consider a historical context of environmental issues that have shaped modern day business strategies. A conceptual figure and table are used to depict the cumulative business strategies companies adopt in response to the megatrends and five waves – those transforming from passive and reactive to more preventative and proactive strategies such as ecodesign.

Section 3.2 expands on the previous where I describe ecodesign in more detail as it relates to cleaner products. Ecodesign is defined in relation to this research. A number of figures for sustainable innovation are used to orient around the levels of design innovation for sustainability. The section concludes by highlighting some of the barriers to ecodesign adoption, namely the predominant focus on the formal procedures rather than the ”soft” or social practices. It also provides an overview of the theoretical and empirical ecodesign studies that address this research gap.

In section 3.3 I introduce communities of practice as a theoretical concept for situated learning. The conceptual origins, the characteristics which define a practice community and the elements that can support participation and learning are all described in this section. The principles conducive to cultivating, supporting and sustaining a community of practice are also elaborated on.

3.1. SUSTAINABILITY CHALLENGES AND BUSINESS RESPONSES

3.1.1. WAVES OF ENVIRONMENTAL CONCERN

Climate change, resource scarcity, globalization, digitalization, shifting economic powers and demographic shifts in populations, wealth and urbanization are some of the prevailing megatrends that are shaping our modern world, driving markets and influencing companies in significant ways (PwC 2014). These global, socio-economic forces have direct and long term social, technological, economic, political and environmental implications. Megatrends are synonymous to Rittel & Webber's (1973) "wicked problems" and have three key characteristics: they mutate over time, their causes and effects are scientifically uncertain, and they involve value conflicts among different societal stakeholders (Dentoni & Bitzer 2013). Given their complexly interconnected nature e.g. international and intergenerational, they require new forms of collective action from multi-levels to generate impactful change in organizations and systems (Dentoni & Bitzer 2015). Elkington et al. (2015) depicts these megatrends metaphorically as elements within a pressure cooker whereby profound changes and solutions are needed (Figure 3-1).

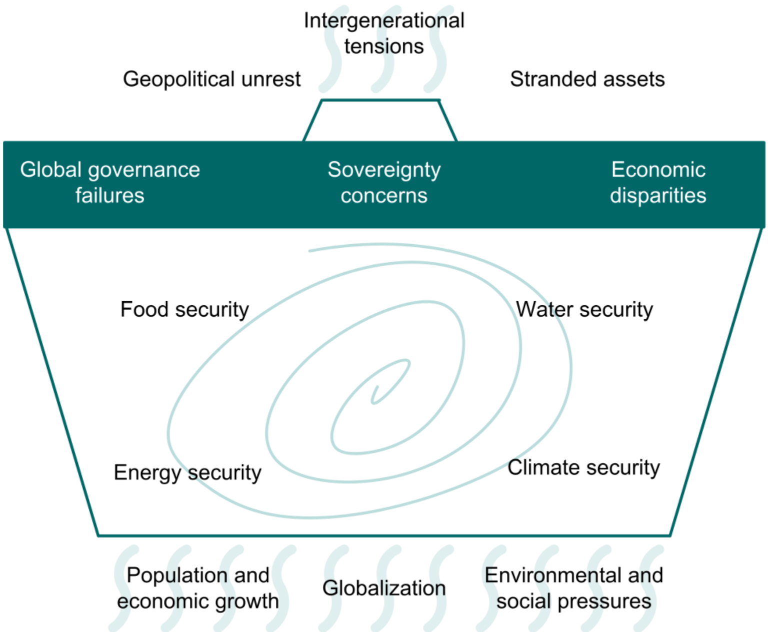

FIGURE 3-1. PRESSURE COOKER METAPHOR FOR THE MEGATRENDS (ADAPTED FROM ELKINGTON ET AL. 2015)

Modern society is characterised by population and economic growth and a simultaneous increase in demand for resources. To highlight a few trends, global population is increasing by more than 70 million each year (WPB 2016) while the global middle class is expanding from 1.8 billion in 2009 to 4.9 billion by 2030 and beginning to imitate western consumption styles (OECD 2012). Resource demands for food, water, energy and other raw materials increase exponentially with population increases and demographic shifts such as these. Within the 20th century, global fossil fuel use increased by a factor of 12 and material extraction increased 34 times (European Commission 2011a). Meeting these increasing demands puts significant pressure on natural resources and on companies through price and supply volatilities. Considering these megatrends, current forms of production and consumption follow a linear take-make-waste approach and are no longer viable. The earth is a closed system with finite resources with the exception of energy.

The resulting state of the environment has been increasingly addressed on political and business agendas since 1960s. Elkington (2006) has portrayed these events in five waves of environmental activism, which are described below and depicted in Figure 3-2. The roles of governments and industry have changed in response to each of these waves, becoming successive over time.

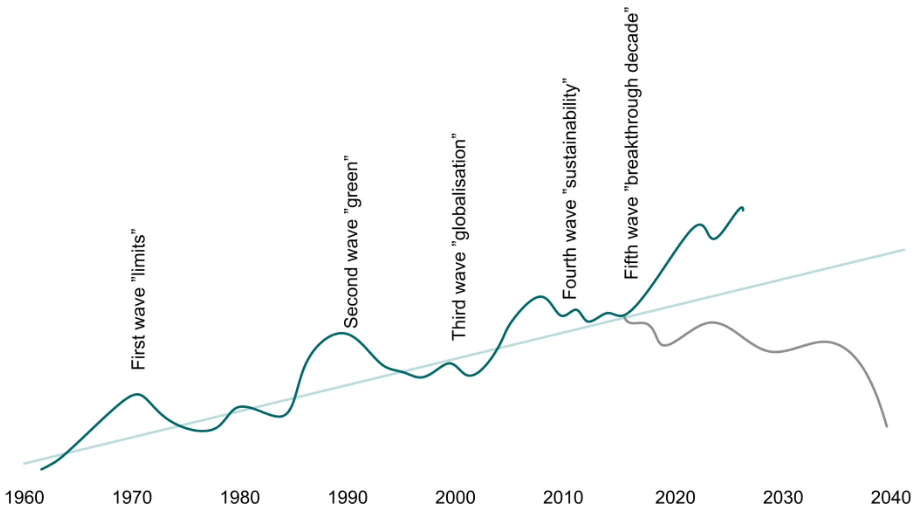

FIGURE 3-2. FIVE PRESSURE WAVES BETWEEN 1960 AND 2040 (ADAPTED FROM ELKINGTON 2006; ELKINGTON ET AL. 2015)

The first wave "limits" occurred between late 1960s and 1970s. The United Nations Conference on the Human Environment was held in Stockholm in 1972 where for the first time, human activities were linked with environmental impacts and the earth's finite resources (Elkington's 2006). It succeeded in generating an international debate and understanding of society's impacts on the environment. The report *Limits to Growth* was also commissioned by the Club of Rome that year, warning of the exponential growth of five variables: population, industrialization, pollution, food, and resource depletion (Spangenberg 2001).

Linked to this was Ehrlich & Holdren's (1972) I=PAT equation that was devised to demonstrate the impact of human activities on the natural environment. The equation subsumes a variety of these megatrends, or what Ehrlich (2014) refers to as the "perfect storm" of environmental and social problems. Environmental impact (I) is expressed as the product of population size (P), affluence level or per-capita consumption (A) and technologies (T) used to supply each unit of consumption (Figure 3-3). It was presumed that environmental impact could be reduced by controlling any (or all) of the three factors. Although simplistic, the equation is a basis for determining the relations between population, economic growth and technological advancement and their contributions to environmental degradation (Chertow 2001).

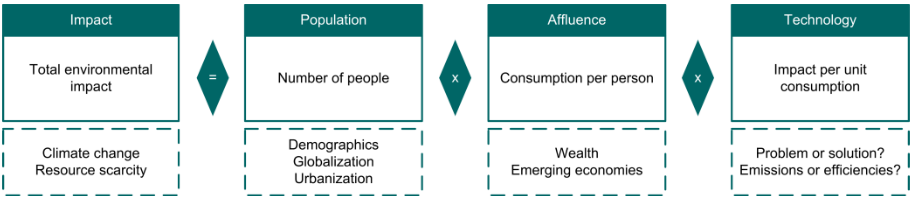

FIGURE 3-3. I=PAT EQUATION FOR DETERMINING THE ENVIRONMENTAL IMPACT (EHRLICH & HOLDREN 1972)

The second wave "green" occurring between 1980s and mid-1990s, called for new kinds of products and production technologies from business (Elkington's 2006). The publication of *Our Common Future,* also known as the *Brundtland Report*, became a landmark report (Bermejo 2014) after the United Nations World Commission on Environment and Development (WCED) defined sustainable development as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (WCED 1987, p.43). As a concept, sustainable development addresses two key challenges: 1) meeting the essential needs of the world's poor and 2) sustaining the environment's ability to meet present and future needs (WCED 1987, p.43). Although the term has been used in many ways (Mukherjee et al. 2016), WCED's definition remains the most frequently cited (Carroll 2015).

Prior to the UN Earth Summit in 1992, the *World Scientists' Warning to Humanity* was signed by over 1,700 of the world's leading scientists. The warning declared: *"human beings and the natural world are on a collision course"* (UCS 1992). The magnitude of this threat was linked to I=PAT e.g. increases in population and trends in production and consumption that affected resource use, climate change, pollution and loss in biodiversity. Agenda 21 was the outcome of the Earth Summit held in Rio de Janeiro. It provided a set of non-binding goals related to sustainable development, including specific recommendations for strengthening the role of business and industry (UN 1992, p.289). For example, it emphasized technological innovations in I=PAT by calling for more efficient production processes and cleaner technologies. This signified new relations between production, policy and environment and strengthened the fields of ecological modernization (Welch 2015) and sustainable consumption and production (SCP) (Charter et al. 2001). Also during this time, eco-efficiency was coined by the World Business Council for Sustainable Development (WBCSD). It emphasized the links between environmental improvements and economic benefits and provided a means for companies to implement Agenda 21 (Schmidheiny 1992). Furthermore, a range of voluntary market standards emerged during this time e.g. the Global Reporting Initiative (GRI) and ISO 14001.

Changes in the interpretation of technology (T) as saviour rather than culprit occurred, where industrial ecologist began to see technological innovations as a means to compensate for the impacts associated with more people (P) and increasing affluence (A), and can thereby contribute to SCP (Chertow 2001). Green growth was coined as an alternative to the conventional economic growth model and seen as a way to foster sustainable development. Conceptual variants included Factor 4 (von Weizsäcker et al. 1997), Factor X (Reijnders 1998) and Factor 10 (Schmidt-Bleek 2008). Although the metric values continue to be a matter of debate, the concepts are complimentary and useful for companies to measure their performance in terms of eco-efficiency (Robèrt et al. 2002).

The third wave "globalization" occurring between late 1990s and 2000s, focused on governance and put a renewed emphasis on government and society (Elkington 2006). In 2002 the UN World Summit on Sustainable Development (WSSD), also known as Rio+10, took place in Johannesburg. It resulted in the "Johannesburg Declaration" which set implementation strategies and established partnerships for achieving the Millennium Development Goals that had been previously launched in 2000 and more recently replaced by the Sustainable Development Goals in 2015.

Elkington has described two additional waves: a fourth wave "sustainability" spanning 2005 to 2012 and a fifth wave "breakthrough decade" occurring between 2015 and 2025 (Elkington 2014). In the former wave, an emergence of many theories of change occurred including an emphasis on the role of entrepreneurs e.g. cleantech, social and venture philanthropy. Integrated reporting and shared value were other concepts embraced by companies during this time. In the latter wave, the emergence of IT e.g. internet of things and new business models such as the circular economy and product service systems, are predicted to significantly transform sustainability and companies alike.

However, this expansive account of environmental pressure waves leads us to an essential question: can sustainable development be attained? Two domains of thought exist: the first views sustainable development as a final destination (goal oriented) while the second views it as an endless journey (process oriented) (Dernbach 2002). The goal oriented view is more critical in stance and calls for radical changes for sustainable development while the process oriented view, and dominant domain, takes a functionalist approach based on adaptive and continuous improvements (Milne et al. 2006). It is difficult to separate one from the other because an end point is needed to direct the journey. But just as the journey can change directions so too can the final destination. In any case, sustainable development corresponds to a journey in this research.

Sustainable development requires multi-level approaches based on systems thinking, collaboration and adaptive learning between different types of people (Geels 2002; Kemp et al. 2007; Kuhndt 2004; Milne et al. 2006). The quadruple helix identifies the main actors and their interconnections as partnerships for developing knowledge and innovation for socio-ecological transitions (Cavallini et al. 2016):

- Governance actors for outlining policy instruments and targets to ensure industry and societal actors adopt sustainable practices (governance space).
- Industry actors for implementing sustainable business practices in industrial value chains (innovation space).
- University or research actors for conducting state-of-art sustainability research (knowledge space).
- Civil society actors for adopting sustainable lifestyles and consumption patterns. (what space?).

3.1.2. EVOLVING BUSINESS PRACTICES FOR THE ENVIRONMENT

Companies have a significant role to play in achieving sustainable development (Pingeot 2014). Sukhdev (2013) affirms this by stating:

> *"Corporations produce almost everything we consume, generating 60 percent of global gross domestic product and providing a comparable share of global employment. Their advertising creates and drives consumer demand. Their production feeds this demand and drives economic growth. Corporations thus drive our economic system, but the way they have been operating also threatens the system's very survival"* (p.143).

The megatrends and pressure waves Elkington (2006) proposed have influenced the way companies perceive and address environmental challenges. As a result, their understanding of environmental challenges has broadened and they have adopted a spectrum of sustainable business practices over the past five decades. A number of authors have categorized these emergent business strategies (see Adams et al. 2012; Altman 1994; Carroll 2015; Hoffman & Georg 2013, Elkington 2006; Elkington & Braun 2013; Kraaijenhagen et al. 2016; Laasch & Conaway 2015; Mukherjee et al. 2016; Post & PWC 2011; Remmen 2001; Schmidt & Remmen 2013; Tilt 2002). Reactive and single-issue approaches have been replaced by preventative and integrated approaches as depicted in Figure 3-4 and outlined below in Table 3-1. Remmen (2006) describes this progression as a cumulative transformation while Stikker (1997) refers to it as the "Environmental Learning Curve".

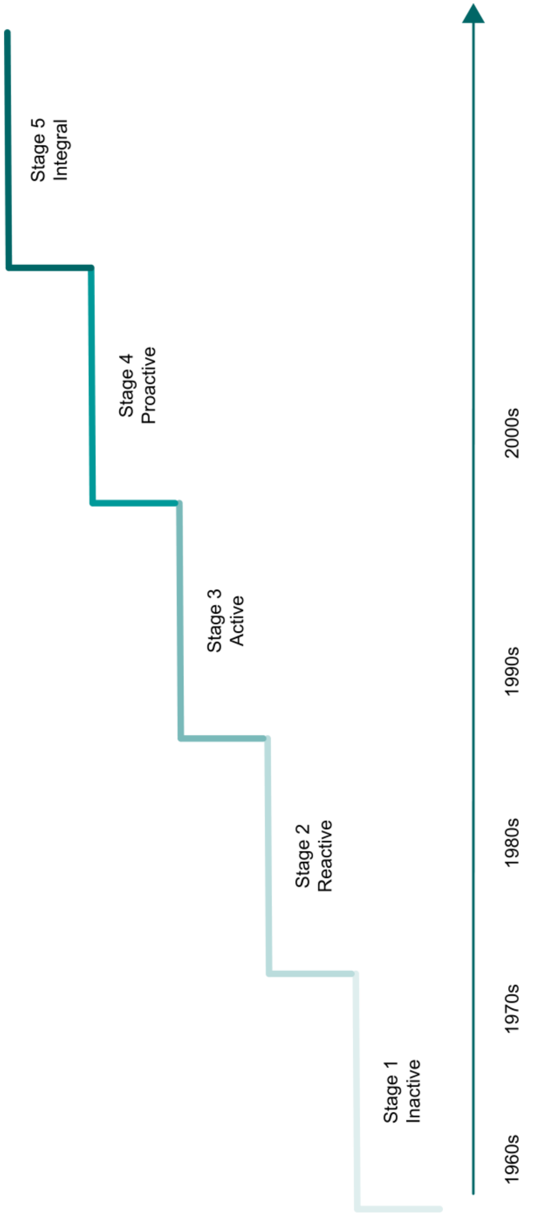

FIGURE 3-4. CUMULATIVE TRANSFORMATION IN BUSINESS STRATEGIES FOR SUSTAINABLE DEVELOPMENT (BASED ON POST & ALTMAN 1994; REMMEN 2001; REMMEN & MÜNSTER 2003; REMMEN 2006; PWC 2011; SCHMIDT & REMMEN 2013; KRAAIJENHAGEN ET AL. 2016)

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Years	1960s-1970s	1970s-1980s	1980s-1990s	1990s-2000s	2000s onwards
Response	Inactive	Reactive	Active	Proactive	Integral
Drivers	Compliant: must do for risk aversion	Compliant: should do for cost savings from operational efficiencies Compliant: must do for risk aversion	Market creation: expected to do for improved image	Market creation: smart to do for eco innovation and advantages	Value creation: envisioned for social innovation and resource scarcity
Strategies	End of pipe	Cleaner production	Environmental management, CSR	Cleaner products	Social value
Practices	Dilution, license to operate, command and control	Pollution control and abatement, best available technology	Continuous improvement	Life cycle thinking	Systems thinking, new business models, circularity
Actors	Differentiated e.g. authorities, NGOs	Differentiated e.g. authorities, NGOs	Differentiated to multi-disciplinary e.g. EHS, marketing	Multi-disciplinary e.g. R&D, procurement, suppliers	Multi-disciplinary e.g. leadership, competitors societal actors

TABLE 3-1. SUMMARY OF TRANSFORMATIONS IN BUSINESS STRATEGIES FOR SUSTAINABLE DEVELOPMENT (POST & ALTMAN 1994; REMMEN 2001, 2006; REMMEN & MUNSTER 2003; PWC 2011; SCHMIDT & REMMEN 2013; KRAAIJENHAGEN ET AL. 2016)

Despite increases in environmental awareness in the 1960s and 1970s, business responses in the first stage were defensive and to some degree, inactive. Companies focused on their own production sites in relation to hazardous substances, effluents and emissions. Collaboration was internally differentiated and externally limited to authorities and NGOs.

The second stage, spanning the 1980s, represented a reactive stance from business. Companies continued to focus on their own production facilities and applied cleaner production methods to achieve cost savings through resource efficiency.

Companies began to be more active in the 1990s, corresponding to the third stage. Governmental regulation shifted to self-regulation with the introduction of environmental management systems and publication of the first international environmental standard ISO 14001 in 1996. Focus broadened to the entire organization, where environmental improvements were systematized and based on continuous improvements. Elkington's (1994) Triple Bottom Line (TBL, 3BL) and People, Planet, Profit (3P) also emerged as concepts. A parallel trend was with all of the discussions on corporate social responsibility (CSR) in response to globalization. The terms suggest that business value is enhanced when a company's financial bottom line is extended to include social and environmental concerns. This emergence represented a turning point because economy and environment were perceived as compatible with one another (Carroll, 2015).

Sustainable consumption and production (SCP) later emerged and implies a shift to more sustainable patterns of production and consumption. More specifically,

> *"The production and consumption of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of a product or service so as to not jeopardize the needs of future generations"* (UNEP 2010a, p.44).

In 2001, the European Commission adopted a Green Paper on Integrated Product Policy (IPP) which became an overall framework of policy instruments for Life Cycle Thinking (LCT) and greener products. Green Public Procurement, Life Cycle Assessment (LCA), Ecodesign, Eco-labels and Environmental Product Declarations (EPDs) became sub-themes to the IPP framework. The fourth stage corresponds with the emergence of SCP and IPP. Companies began to proactively focus on the environmental impacts across a products life cycle and eco-innovation and market creation became key drivers. Collaboration became more multi-disciplinary, involving R&D and Procurement functions as well as actors across the supply chain. This stage is where my research takes point of departure in.

The fifth stage represents an integral business response and the current era for sustainable business strategies. The linear “take-make-dispose” paradigm has shifted to a circular model of renewal that puts significant emphasis on collaboration. In 2011, the European Commission published The Roadmap to a Resource Efficient Europe, which outlined how Europe's economy could be transformed into a sustainable one by 2050. In connection to this, The Circular Economy Package was adopted in 2015. The Circular Economy continues to emerge and is defined as:

> *“An economy in which stakeholders collaborate in order to maximise the value of products and materials, and as such contribute to minimising the depletion of natural resources and create positive societal and environmental impact”* (Kraaijenhagen et al. 2016, p.14).

Porter & Kramer’s (2011) shared value is another modern business practice where leaders of companies must innovate to reshape the relationship between their business and society. Whether the purpose is to address resource scarcity or improve social equity, new business models are sought after as well as new forms of collaboration with a broader range of organizations and societal actors from which the company operates (cf. quadruple helix in 3.1.1).

3.2. ECODESIGN AND SUSTAINABLE INNOVATIONS

Ecodesign is a business practice for reducing the environmental impacts associated with products, technologies and services hereafter referred to as products (cf. IPAT equation in 3.1.1). Ecodesign is defined, and understood in this research, as:

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

Similar concepts include green design (Mackenzie 1997), design for the environment (DfE) (van Hemel 1998), environmentally conscious design (Zhang et al. 1997), product oriented environmental management (Rocha & Brezet 1999), and design for sustainability (Spangenberg et al. 2010). I have chosen to use ecodesign throughout the thesis since it is the established term in European literature and because this research is funded by European institutes. However, DfE is used within the case company because it originates from the *Design for X* concept which is frequently used in industry (this is elaborated on in Chapter 7).

The introduction of environmental aspects into the design process dates back to the 1970s with Victor Papanek’s book *Design for the Real World: Human Ecology and Social Change* (1971). Advocating for socially and ecologically responsible design, Papanek centralized the role of designers and criticized their neglect of the wider problems. He further defined design responsibility as engagement with "real problems" and the designer as “a bridge between human needs, culture and ecology” (Keitsch 2012, p.183).

Ecodesign re-emerged as a concept in the 1990s (cf. Figure 3-4 and Table 3-1). Initial emphasis was placed on the role of designers and the LCA methodology emerged for assessing the environmental performance of products. Also during this time, Andreasen & Olesen's (1990) Theory of Dispositions described the interrelations between decisions in product development, where early decisions to some extent determine the outcome of later decisions. Based on this, it became widely asserted that up to 80% of a product’s environmental impacts are determined during the early stages of design (Charter 2001; European Commission 2014; McAloone & Bey 2009). Figure 3-5 represents a typical product development process. The scoping phase is characterized as the fuzzy front end of design, where the majority of strategic decisions are made. Here, knowledge of the product’s potential impacts is low but the ability to reduce or eliminate those impacts is high with environmentally conscious design. As the product development process progresses however, knowledge of the impacts increases while the ability to minimize or eliminate those impacts decreases. Olesen's (1992) work also laid the ground work for establishing concurrency between the life cycles of a product and the interrelations between other cross functional employees (Andreasen & McAloone 2008).

This leads to three aspects of ecodesign: 1) life cycle thinking; and 2) intra- and inter-organizational participation; and 3) innovation types needed. The capacity of ecodesign to contribute to product innovations depends on the extent to which life cycle thinking is applied and stakeholders are engaged (Carrillo-Hermosilla et al., 2010; Quist and Tukker, 2013). Furthermore, product innovations are not possible without organizational changes, or organizational innovation. All of these aspects are briefly discussed below.

3.2.1. LIFE CYCLE THINKING

LCT is fundamental to ecodesign (Tischner et al. 2000). It implies that you consider the environmental, social and economic impacts of a product throughout its consecutive and interlinked life cycle stages e.g. from raw material extraction and processing to manufacturing, use and final disposal. LCT expands the established concept of cleaner production, to include the whole product system and is also referred to as the “cradle-to-grave” and “cradle-to-grave” perspectives (Remmen & Münster 2003). The latter emphasizes recycling considerations and a “closed loop” system. While it is not likely the company’s immediate sphere of influence extends the entire product life cycle, design decisions nevertheless have implications for the life cycle (cf. Figure 3-5).

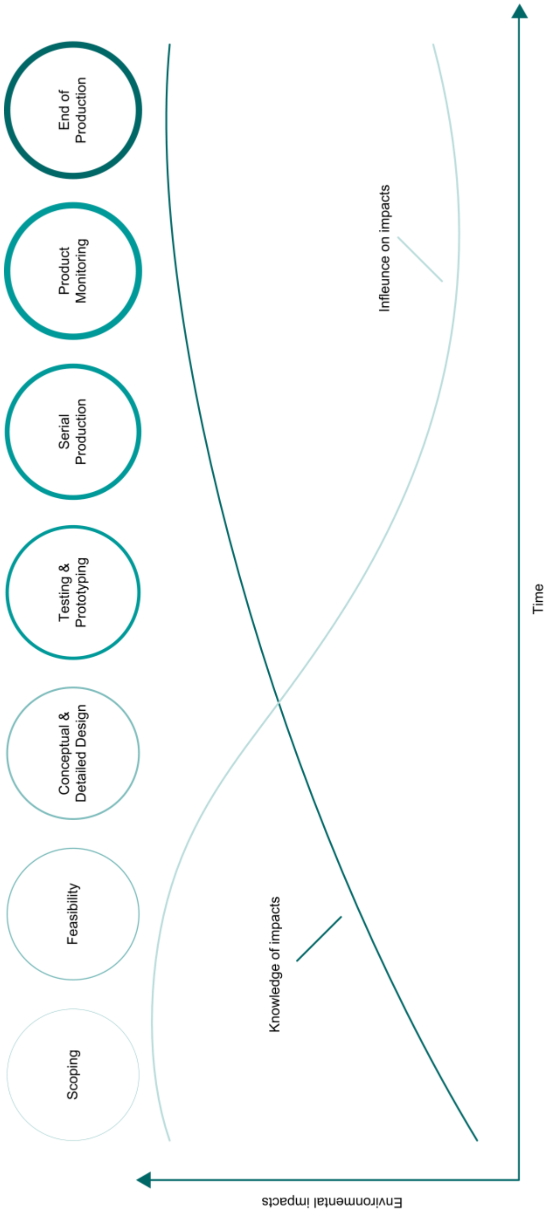

FIGURE 3-5. A TYPICAL PROCESS FOR PRODUCT DEVELOPMENT INDICATING KNOWLEDGE OF, AND INFLUENCE ON, ENVIRONMENTAL IMPACTS (MCALOONE & BEY 2009)

Different tools can be used to support LCT and to weigh the advantages and disadvantages associated with various choices at different life cycle stages. LCA is an established method to quantitatively evaluate these choices and determine a products environmental aspects and impacts (ISO 2006). Other tools can be combined to determine the economic and social impacts of a product, such as life cycle costing and social LCA respectively. Furthermore, a number of guides and standards have been developed to facilitate integration in companies (Brezet & van Hemel 1997; ISO 2002, 2011; McAloone & Bey 2009; Tischner et al. 2000). The following works can be consulted for more extensive taxonomies of ecodesign tools: Bovea & Pérez-Belis (2012); Dekoninck et al. (2016); and Rossi et al. (2016).

However, LCA research is primarily focused on improving the methodology rather than integrating it into business processes for enhanced decision making (Frankl & Rubik 2000). This is contested by Sonnemann & Valdivia (2014) who believe industry is ahead of the curve in LCT and the use of LCA. There are concerns these tools are not used by designers in the design phases due to their time and data requirements (Tischner et al. 2000). Frankl & Rubik (2000) inform that the role of LCA changes depending on the stage of integration; at the beginning LCA is used by companies to learn while in latter stages LCA is used to justify marketing claims about the products.

3.2.2. STAKEHOLDER ENGAGEMENT

Ecodesign literature has traditionally emphasized the role of product designers and engineers. Yet, Johansson et al. (2007) found that few studies focussed on the interface between designers and environmental specialists throughout the product development process. Remmen & Münster (2003) stress the importance of involving a range of intra- and inter-organizational stakeholders beyond just the design and engineering functions. This is because product design is a complicated process and requires inputs from several functional departments. For example, a decision to substitute materials can also affect the procurement team regarding price, the production team regarding technological suitability, the EHS team regarding EHS aspects, etc. The intra-organizational cross functions possibly affected by ecodesign are depicted in Figure 3-6.

As focus shifts from within a company’s fence to the entire product chain there are implications on a wider range of external stakeholders. Using the same example, material substitution can also affect the suppliers regarding technical feasibility or supply availability, the customers and waste handlers regarding recyclability at end of life, etc. The inter-organizational value chain actors possibly affected by ecodesign are depicted in Figure 3-7.

More recently, ecodesign literature has begun to highlight the importance of Project Management functions (Ali et al. 2016; Brones et al. 2014; Huemann & Silvius 2015; Marcelino-Sádaba et al. 2015; Martens & Carvalho 2015; Økland 2015; Sánchez

2015). Further, research on the integration of sustainability with complex product systems (CoPS) (Hobday et al. 2000) and mega construction projects (MCP) (Mok et al. 2015; Shen et al. 2017; Zeng et al. 2015) are increasing since there are often more institutional requirements related to financing and a closer association with public interests. Lenferink et al. (2013) propose three strategies for more sustainable infrastructure development: green procurement, strategic asset management and relational contracting.

The involvement of internal and external stakeholders from all hierarchical levels is thus a requirement for ecodesign (Laasch & Conaway 2016). Since SWP does not produce a standard product but rather a customized project, this is requiring the coordination of many internal and external stakeholders beyond the traditional product development function.

FIGURE 3-6. INTRA-ORGANIZATIONAL RELATIONS AMONG CROSS FUNCTIONS (REMMEN & MÜNSTER 2003)

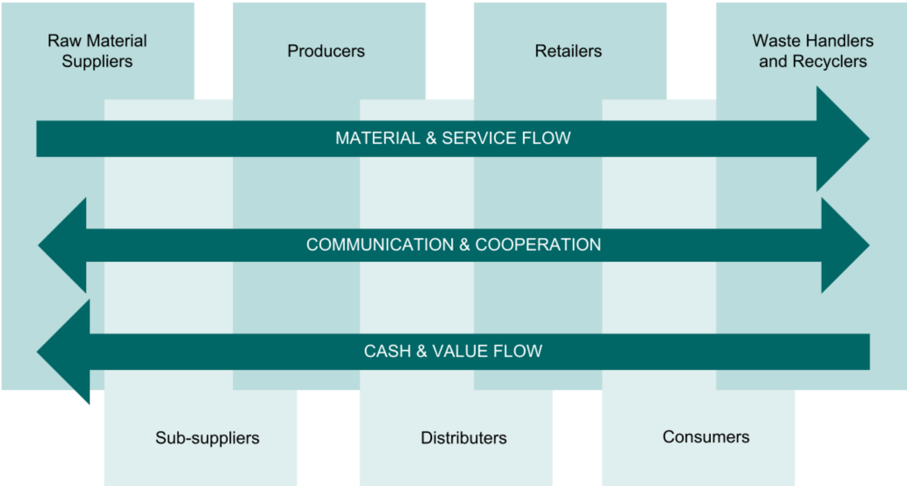

FIGURE 3-7. INTER-ORGANIZATIONAL RELATIONS ACROSS VALUE CHAINS (REMMEN & MÜNSTER 2003)

3.2.3. SUSTAINABLE INNOVATIONS

Based on the discussions around stakeholder relations, ecodesign goes beyond just the redesign of products, as it requires multiple levels of change (cf. quadruple helix in 3.1.1). Gaziulusoy & Brezet (2016) combine two former models to describe these levels of change related to design innovation for sustainability. In the first model, Brezet (1997) (Figure 3-8) presents four levels of sustainable innovation for product development: 1) product improvement; 2) product redesign; 3) function innovation; and 4) system innovation.

The second model (see Figure 3-9) was developed by Adams et al. (2012) based on a literature review of sustainability-oriented innovations. It shows three contexts of sustainability-oriented innovation: 1) operational optimization; 2) organizational transformation; and 3) systems building. It is further divided into three axes: 1) innovation focus (technical to socio-technical); 2) company's view of itself in relation to society (insular to systemic); and 3) the extent to which innovation extends across the firm (stand-alone to integrated). As a company seeks to be more sustainable, it must innovate its operations and products so that they bring social value while suffusing sustainable innovations throughout the organization (vision, strategy, processes, cross functional practices and culture), and extend beyond its own operations and engage with stakeholders to facilitate change in wider systems.

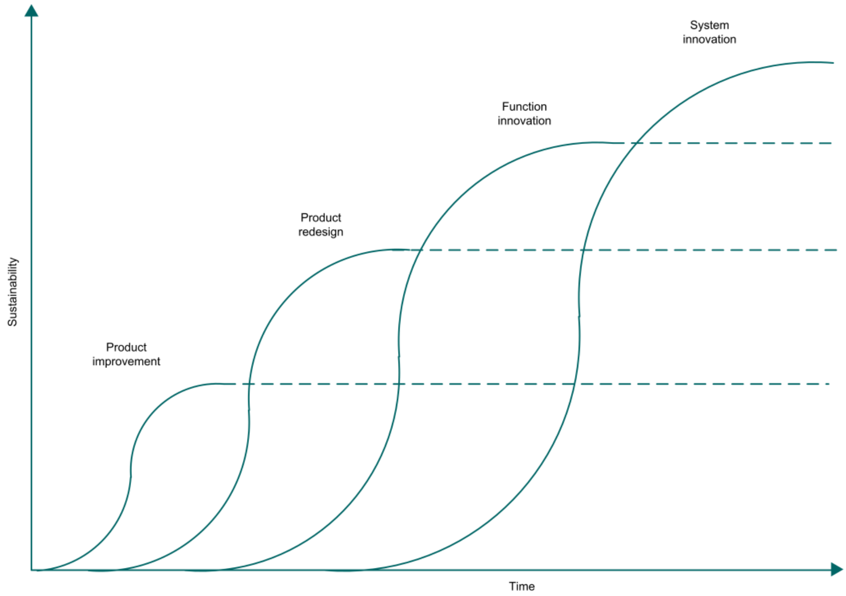

FIGURE 3-8. LEVELS OF PRODUCT INNOVATION FOR SUSTAINABILITY (BREZET 1997)

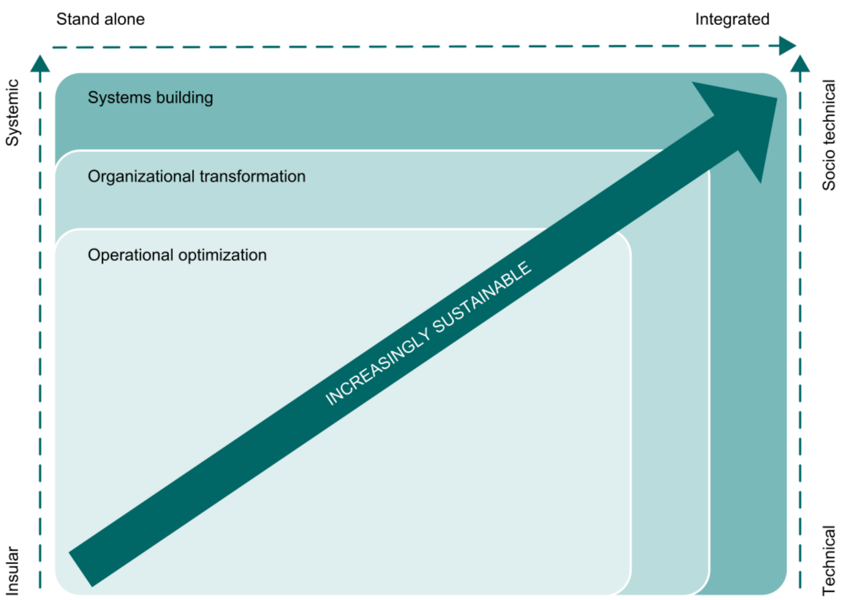

FIGURE 3-9. THREE CONTEXTS OF SUSTAINABILITY ORIENTED INNOVATION (ADAMS ET AL. 2012)

Gaziulusoy & Brezet's (2016) resulting model can be seen in Figure 3-10. As reported by Pigosso et al. (2015) companies have especially gone beyond their own company borders the last five years, while Adams et al. (2012) inform that companies can be ambidextrous and operate in more than one level. Many contest that a sustainable company in the context of systems innovation does not yet exist despite a number of firms who are experimenting in that direction (Adams et al. 2012; Gaziulusoy's 2010). This is because innovation at the systems level requires not just technological or organizational change but institutional change e.g. change to norms, values, socio-cultural practices and the underlying assumptions of our current economic system. Thus companies and designers face challenges that are unparalleled in scale to previous business or design challenges.

Other methods are needed in addition to ecodesign if socio-technical changes are to be achieved. These are effectively depicted in Ceschin & Gaziulusoy's (2016) DfS evolutionary model. Tyl et al. (2015) ecodesign research suggests designers use the concept of local value creation, or social value, to help develop more eco-innovative products, services and business models. The figure also reiterates Pigosso et al. (2015) description of ecodesign as:

> *"A multidisciplinary research area that is continuously optimizing the foundations and expanding the borders"* (p.413).

As previously stated (cf. Chapter 1), the intent of this thesis was not to focus on the specific product innovations but rather innovations to the design processes and design practices at SWP. Therefore, it is important to differentiate the product innovations described above and the organizational innovations, or changes to organizational practices, which are also necessary within the company. Organizational innovations refer to:

> *"The implementation of new organisational methods in a firm's business practices, workplace organisation or external relations"* (OECD & European Union 2005, p.51).

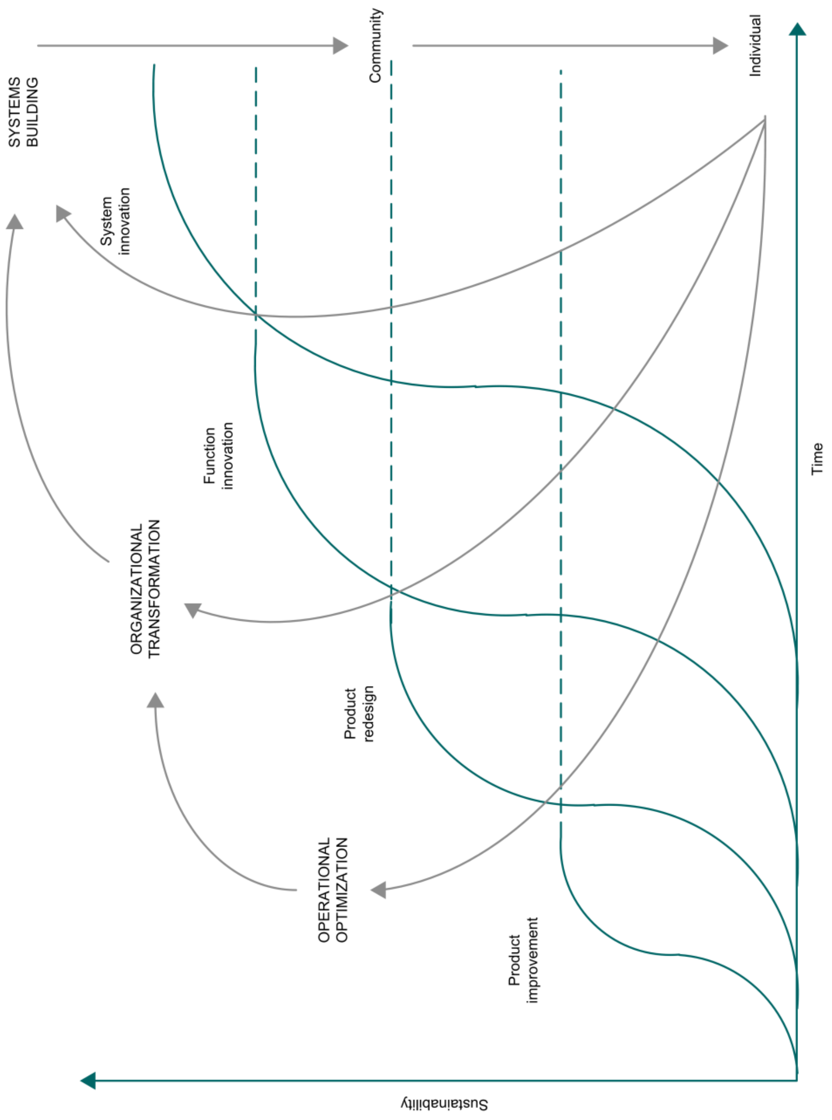

FIGURE 3-10. THE CONTEXTS OF CHANGE IN RELATION TO LEVELS OF DESIGN INNOVATION FOR SUSTAINABILITY (GAZIULUSOY & BREZET 2016)

3.2.4. ORGANIZATIONAL LEARNING

Ecodesign continues to evolve as a concept in terms of theoretical and methodological frameworks (Pigosso et al. 2015: cf. Figure 3-4). Despite this, the adoption rate in companies remains low and "best" ecodesign practices lag (Bey et al. 2013; Dekoninck et al. 2016; Rossi et al. 2016). This is referred to this as the implementation gap between theory and practice (Baumann et al. 2002; Knight & Jenkins 2009).

Organizational change remains a central aspect because practices related to product development must be changed in order to effectively integrate environmental aspects in product innovation processes. Ecodesign research has begun to more consistently reference change management and the "soft" side of ecodesign (Brones et al. 2016; Lozano 2012; Verhulst 2012; Verhulst et al. 2007). In Table 3-2, representative literature is presented in chronological order to show this increasing trend of using organizational change and a learning approach to change.

TABLE 3-2. CHRONOLOGICAL LIST OF ECODESIGN LITERATURE USING ORGANIZATIONAL CHANGE AND A LEARNING APPROACH TO CHANGE

Source	Research outcome
Keogh & Polonsky (1998)	Advocated for the use of green teams to generate ideas and enhance learning through experiences with environmental activities. Also investigated issues in a team approach.
Remmen & Lorentzen (2000) ♦	Focus on employee participation in the implementation of cleaner technology and more broadly, the learning processes in environmental teams
Cohen-Rosenthal (2000) ♦	Encouraged the "soft" components of industrial ecology e.g. social processes, human resource strategies, learning organizational constructs, etc. and advocated for their inclusion to enhance environmental practice.
Charter (2001) ♦	Explored the organizational context of ecodesign and provided a series of company examples of implementation.
Benn et al. (2006)	Investigated the process of sustainable change in companies, with a focus on human resources and business strategies. Proposed an integrated phase model for understanding how companies move from compliance to strategic sustainability, with a specific focus on change agents.
Boks (2006)	Studied the social and psychological aspects and intangible processes that could affect ecodesign implementation.
Stone (2006a) ♦	Identified a set of key internal organizational factors contributing to the uptake of cleaner production.
Stone (2006b) ♦	Presented a framework to enhance the performance of cleaner production or

	similar environmental programs.
Johansson et al. (2007) ♦	Evaluated the organizational and technological mechanisms supporting ecodesign integration and collaboration between product designers and environmental specialists.
Verhulst et al. (2007)	Described several aspects of change management in order to formulate several propositions relating to the implementation of life cycle thinking and sustainable design.
Benn & Baker (2009) ♦	Contrasted organizational development and organizational change theories in light of the relationship between human and ecological systems.
Lozano (2012) ♦	Presented an institutional framework to help orchestrate organizational change and institutionalize corporate sustainability.
Verhulst & Boks (2012) ♦	Developed a model for sustainable design implementation, focussing on three levels: 1) the implementation steps; 2) the social practices; and 3) the employees or departments.
Verhulst et al. (2012) ♦	Presented four groups of social practices and discussed how they influence the implementation process of sustainable product innovations: 1) resistance; 2) internal communication; 3) empowerment; and 4) organisational culture.
Zahari & Thurasamy (2012)	Presented a conceptual model of the relationship between a firm's human resource capabilities and technological capabilities for green product innovation.
Novak (2014) ♦♦	Investigated how and why the management of sustainability values poses a challenge for a design team. The design team is evaluated through the lens of a learning organization, which is grounded in systems thinking.
MacDonald & She (2015)	Focussed on pro-environmental behaviour and seven cognitive concepts important to ecodesign: 1) responsibility; 2) decision making skills; 3) decision heuristics; 4) altruism; 5) trust; 6) cognitive dissonance and guilt; and 7) motivation.
Brones et al. (2016) ♦	Proposed an ecodesign transition framework with a focus on the "soft" side of ecodesign through transition management and organizational change theories.
Skelton et al. (2016) ♦♦	Applied Etienne Wenger's CoP approach to the existing environmental and product development practices of two Danish case companies.

♦ Indicates empirical research was carried out ♦ Indicates a learning approach to change was used

Although publications on business and the environment have reached a consensus on the need for change, the way in which change is achieved is commonly disputed (Schaeger & Harvey 2000). This is because change can be addressed in many ways e.g. from strategic perspectives, developmental perspectives, etc. Gladwin (1993) identifies six possible approaches to environmental change: 1) greening as institutionalization; 2) greening as organizational learning; 3) greening as natural selection; 4) greening as strategic choice; 5) greening as transformational leadership; and 6) greening as organizational evolution.

This research is linked to organizational change from the perspective of organizational learning. First, I suggest that the low adoption rate of ecodesign has been due to a predominant focus on formal procedures rather than social practices, otherwise designated the “soft” side of ecodesign (Boks 2006). Magnusson (2000) admits that a significant amount of ecodesign literature concerns manuals, guidelines and tools indicating a research domain that is technical, practical and normative in character. Similarly, Stone (2006a) stresses the importance of taking a humanistic (rather than mechanistic) approach and asserts that procedures and tools do not generate the necessary change for integration. Second, I hypothesize that the integration of ecodesign requires organizational learning about environmental issues and this learning process happens in the course of action. Thus, learning and participation are necessary social practices for change and will briefly be elaborated below:

Learning: Stone (2006b) informs of the lack of social structures to support reflective learning and thereby environmental improvements and change in companies. While, Novak (2014) informs that people are both agents of organizational learning and members of a learning organization which influences links between learning, knowing and acting. Furthermore, organizational structures can be set up in a way that enhances employees’ ability to learn from one another.

Participation: Verhulst et al. (2012) identify empowerment and participation important for sustainable product innovations. While Georg & Fussel (2000) have suggested that greening is a matter of sense-making in which environmental commitment emerges from a process of social interaction. Allocating responsibility to employees in projects; appointing ambassadors; forming committees; or creating tasks related to sustainability are all ways in which to empower and involve employees. Furthermore, training and communication around sustainability were both found to be meaningful aspects of empowerment. Internal champions also play a vital role in the integration process. Thus, companies should ensure employees are involved at the onset of integration.

Ecodesign procedures should thus be combined with organizational processes that facilitate the social practices such as participation and learning (Halme 1997). The next chapter introduces Wenger’s (1998) theory of communities of practice.

3.3. COMMUNITIES OF PRACTICE AS AN ANALYTICAL CONSTRUCT

I start by defining practice communities and introducing their origins, and then I expand on some specific conceptual elements that I found useful for my research. The concept of Communities of Practice (CoP) is rooted within the learning sciences and associated with practice-based learning. Lave & Wenger (1991) are credited for coining the term and using it to explain learning through participatory practice in order to critique former cognitive learning theories. CoP imply that learning is the outcome of social processes rather than an individual cognitive process in one's head. Knowledge is embedded in the social practices of a community where learning is thus shaped by, and interwoven with, specific cultural and social contexts. In this sense, practice based learning is said to be a continuous, dynamic, engaged, situated and identity-forming process.

A social learning theory consists of four components of learning: meaning, practice, community and identity. These four components are depicted in Figure 3-11. Meaning is our changing ability to experience the world as meaningful, both individually and collectively (learning as experience). Practice is our shared historical and social resources, frameworks and perspectives that sustain mutual engagement in action (learning as doing). Community is our social configurations in which the value of our enterprise is defined and our participation is recognisable as knowledge (learning as belonging). Identity is how learning changes who we are individually and within the context of the community (learning as becoming).

To understand and appreciate the different interpretations of CoP, I describe the evolution and characteristics of CoP as a concept in the following paragraphs. A summary of the different interpretations is provided in Table 3-3. As I previously described, individual and collective learning occur in parallel to one another. CoP are closely related to Senge's (1990) learning organization theory that is grounded in collaborative learning and professional learning communities. He defines learning organizations as:

> *"Organizations where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning to see the whole together"* (p.3).

In Lave & Wenger's (1991) original work also focuses on workplace learning and professional communities. They use the term "situated learning" to describe the acquirement of skills in organizational groups such as midwives, tailors and butchers, where learning is a result of experiential story sharing and problem solving in informal settings between experts and novices. Clinical placements and apprenticeships are closely linked to this conceptualized form of learning. The term "legitimate peripheral participation" relates to the novice practitioners who accrue knowledge over time, reach a point of skill mastery and become the experts who mentor newcomers. The authors describe a CoP as a community with common interests and a desire to learn from, and contribute to, this group based on their former experiences. In this interpretation of CoP, emphasis is given to people from the same discipline who develop and refine a similar set of practices rather than new ones. However, they failed to provide a formal definition of CoP in this work.

FIGURE 3-11. COMPONENTS OF SOCIAL LEARNING THEORY (WENGER 1998)

Unknowing of the CoP concept, Brown & Duguid (1991) expanded on Orr's (1990) ethnography of Xerox field technicians. The technicians exchanged stories on how they repaired copy machines in response to insufficient procedural manuals. Brown & Duguid (1991) elaborated on engagements outside of the communities and interactions between workers from different communities. They also proposed three categories of the field technicians' practices: narration representing the exchange of stories, or experiences that could outline a coherent account of the problems; collaboration representing how the technicians informally created a network to make sense of these problems and help one another; and social construction representing individual and shared identities as well as the collectively-held knowledge in the network that resulted from this sharing.

Wenger's (1998) work refocuses on the individual members and dilemmas related to their social identity as a result of their membership in multiple and differing communities. He moves away from the novice-expert relations to define three elements that together constitute a CoP: mutual engagement, joint enterprise and shared repertoire. Mutual engagement represents the relations such as the amount and pattern of interaction among community members. These collective relations are what bind members together as a social entity and it is through this interaction and participation where the community's culture, norms and practices are shaped. Joint enterprise represents the domain of activity and knowledge that affirms the community's purpose and allows for the collective process of negotiation and sense making between members. Member interactions also create a common ground and shared understanding of what binds them together as a community and in this way, the joint enterprise is constantly renegotiated by members. Shared repertoire represents the shared resources, also known as boundary objectives or artefacts, members create or adopt into their practice in order to remain effective in their domain or joint enterprise. Ideas, procedures, techniques, documents, tools, jargon, symbols, or actions represent examples of resources that members share.

In *Cultivating Communities of Practice*, the focus of Wenger et al. (2002) shifts from individual identities and members in communities to how communities can be developed in organizations and how "knowledge workers" can be managed. The authors also revise the three characteristics of CoP to: domain, community and practice. Domain is considered the common ground which defines the community's purpose, the minimal competences of members and the boundaries that guide members' learning and give meaning to their practices. It's synonymous to the joint enterprise in Wenger's (1998) work. Community consists of the members who are invested in the domain and collective learning. As an entity, the community is considered the social fabric for learning and includes the social structures that facilitate communication, the sharing of ideas and relations between members as well as interactive learning. Communities differ based on their various compositions. This characteristics correlates with the former element called mutual engagement. Practice is equivalent to the shared repertoire and represents the sets of knowledge, artefacts and practices members share, maintain and co-develop. In this work the first formal definition of CoP is provided:

> *"CoP are groups of people who share a concept, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis"* (Wenger et al. 2002, p.4).

In the same work they expand on what a CoP is, being:

> *"A group of people who interact, learn together, build relationships and in the process develop a sense of belonging and mutual commitment. Having others share your overall view of the domain and yet bring their*

> *individual perspectives on any given problem creates a social learning system that goes beyond the sum of its parts"* (Wenger et al. 2002, p.34).

Barab et al. (2004) contest that despite a strong theoretical underpinning of the CoP concept Wenger fails to provide an operational definition. Based on his and their own former works, they synthesize eight characteristics of a CoP: 1) shared knowledge, values and beliefs; 2) overlapping history among members; 3) mutual interdependence; 4) mechanisms for reproduction; 5) a common practice and/or mutual enterprise; 6) opportunities for interaction and participation; 7) meaningful relationships; and 8) respect for diverse perspectives and minority views.

From a review of KM publications, Bolisani & Scarso (2014) found that the CoP concept is gaining the interests of both academics and practitioners but they indicate challenges in finding a consensus on a standard definition. The table below demonstrates the ways in which Wegner's definition for CoP has changed over time. In this research, I understand communities as social structures where members are shaped by and contribute to shaping their community through a mutual process of learning, experience sharing, and co-developing practices and artefacts.

TABLE 3-3. THE DEVELOPMENT OF THE CONCEPT COP IN WENGER'S WORK (BOLISANI & SCARSO 2014)

Source	Core aspect	Main points
Lave & Wenger (1991)	First reference to the term	Sociological grounds CoP as self-organizing structures
Wenger (1998)	CoP as social constructions	CoP as social learning systems CoP explain mutual learning and knowledge exchange
Wenger et al. (2002)	CoP as to-be managed structures	CoP as deliberate organizational arrangements Cultivating CoP in business
Wenger (2010)	CoP as ways to reflect on learning mechanisms	Learning process in a social dimension Recognition of "inconsistent uses" of the concept

3.3.1. DUALITY OF MEANING

In a CoP, the constant negotiation of meaning is part of mutually engaging in a joint enterprise and developing a shared repertoire. The negotiation of meaning has two elements: participation and reification (Figure 3-12).

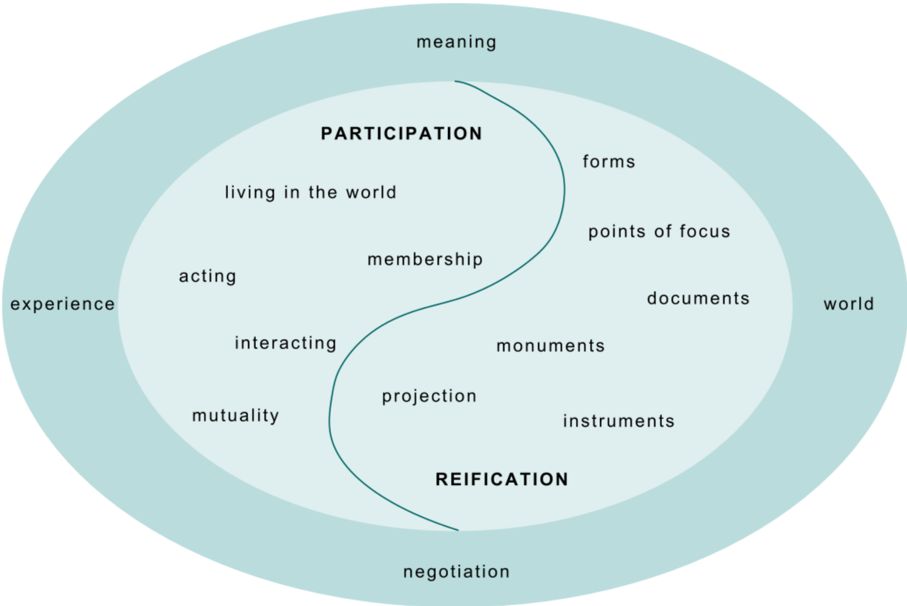

FIGURE 3-12. THE DUALITY OF PARTICIPATION AND REIFICATION (WENGER 1998)

Participation represents both the actions and activities community members engage in, and it is the relation to other people involved in the activities. A member is both influencing and being influenced by the community. Participation can involve many relational forms including harmonious, conflictual and political ones. Further, participation is broader than just one domain of engagement rather it influences our identity and affects our experiences beyond one specific context of engagement. Reification represents the artefacts and processes which give form to the members in communities as they negotiate meaning. Hence, the products of reification are not solely specific, material objects but are also reflections upon practices and symbols of human meaning. Reification has the ability to shape our experience in the sense that using a tool in a specific activity can change the nature of that practice for us. Wenger (1998) cautions about the "double edge" of reification and its dangers, where a dominate focus on artefacts and tools can ossify new practices and negotiation. In this respect, reified forms can become autonomous and inhibit their own identities different from the original contexts which created them.

Figure 3-12 illustrates that participation and reification are not two isolated elements. Rather, they form a duality where they interact and thereby affect each other, which is both fundamental to meaning and the nature of practice. Wenger (1998) calls this the duality of meaning and insists the elements are opposing but rather two inseparable and mutually dependent elements:

> *"A single conceptual unit that is formed by two inseparable and mutually constitutive elements whose inherent tensions and complementarity give the concept richness and dynamism"* (p.66).

Participation and reification are not always equal:

> *"It is through their various combinations that they give rise to a variety of experiences of meaning"* (Wenger 1998, p.62).

However, if participation overshadows reification the risk stands that practices become too vague and there is a lack of concreteness to anchor the practices. While if reification dominates over participation the risk stands that procedures become locked in with little chance for shared experiences through negotiation (Wenger 1998). As Wenger (2010) states:

> *"Artefacts without participation do not carry their own meaning; and participation without artefacts is fleeting, unanchored, and uncoordinated"* (p.1).

A significant amount of companies and ecodesign literature focus on reification. Attention is too often given to developing the "right" tools that give the "best" results as opposed to using the tools such as LCA to develop a culture of awareness, motivate interest in environmental issues and engage in the practice of ecodesign. I further elaborate on this in Chapters 4 and 8.

3.3.2. KNOWLEDGE BOUNDARIES, BOUNDARY OBJECTS AND BROKERS

CoP can take many forms, they can be big or small, long- or short-lived, co-located or distributed, homogeneous or heterogeneous, intra- or inter-organisational, spontaneous or intentional, and unrecognised or institutionalised (Wenger et al. 2002). In this research context, CoP examples include the case company, a business unit, a functional department, a project team, an internal or external knowledge sharing network or an industry association. Further, a CoP is not necessarily formalised and cannot always been seen in the formal procedures of the company, as shown in Figure 3-13 using organisational diagrams.

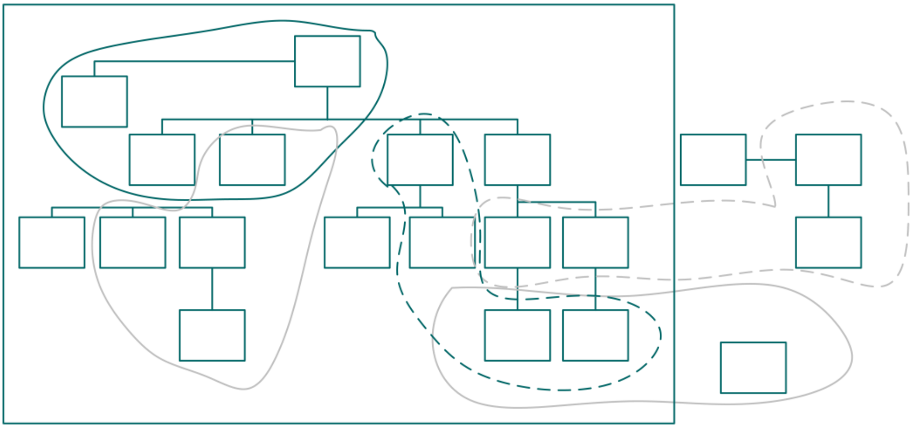

FIGURE 3-13. COMMUNITIES OF PRACTICE DEPICTED AS INFORMAL ORGANIZATIONAL GROUPS (WENGER 2000)

A CoP has its individual characteristics and cultural dynamics based on the type of members, boundary objects, practices, etc. Membership in a community translates a member's identity as a form of competence (Wenger 1998). However, it is not an isolated entity and should not be considered independent from other practices. Instead, it exists in interaction with its surroundings, including other communities. Multi-membership denotes that community members participate in a number of other practice communities and thereby take their experiences and knowledge from one to the other. In this sense, a member can introduce elements of one community's practice to another through a process of brokering. In a similar way, reified artefacts can cross boundaries and enter the practices of different communities (Figure 3-14).

Knowledge boundary is a term used to indicate knowledge gaps within or between communities. Boundaries between communities can lack a negotiated understanding that is more explicit at the core of a community (Wenger 1998). Knowledge is localised, embedded and invested within a function or community's core and boundary crossing can be both a source of, and a barrier to, innovation. Carlile (2002) informs that innovation often occurs at the boundaries of different practice domains and this knowledge must somehow be managed. Difficulties can arise when knowledge from one domain must be shared across boundaries and used in another domain by a different community. This is especially true if the form of knowledge is new to the community who should be applying it. This explains why interdisciplinary collaboration can be problematic, particularly in product development communities.

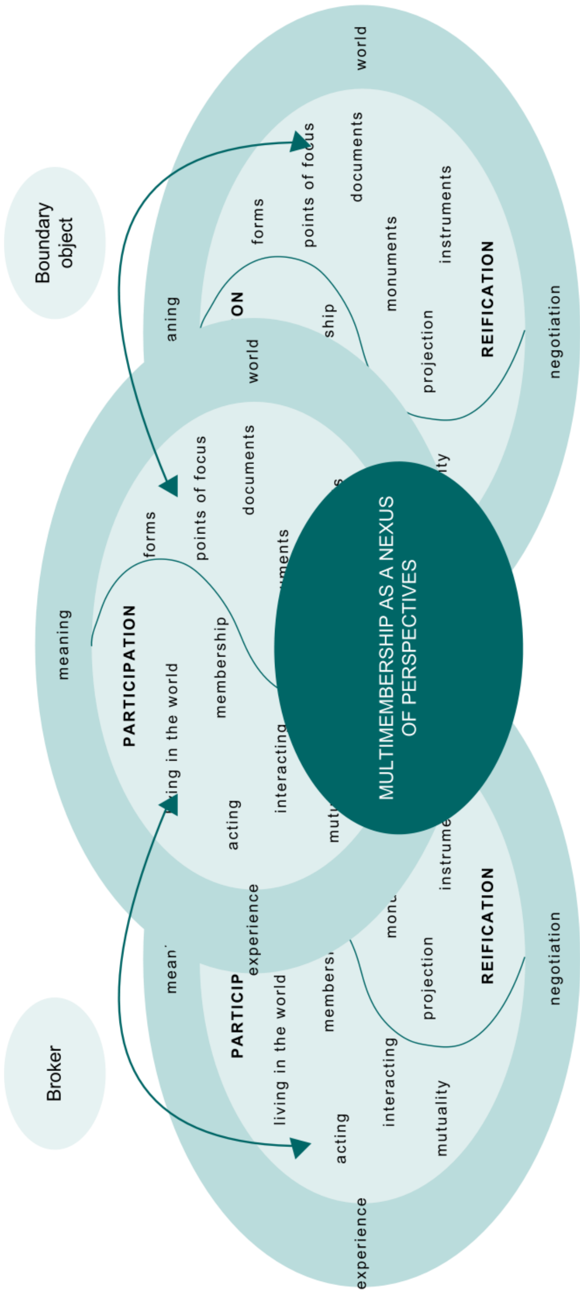

FIGURE 3-14. PARTICIPATION AND REIFICATION AS CONNECTIONS (WENGER 1998)

Carlile (2004) proposes three types of knowledge boundaries: syntactic, semantic and pragmatic as well as three types of processes: transfer, translation and transformation (Figure 3-15). At the lower part of the triangle, differences and dependencies are known and novelty is low between communities but become increasingly complex and ambiguous as one goes up the triangle. At syntactic boundaries, a shared language or syntax for community members to understand and easily transfer their knowledge across domains must be established. If a community does not share these fundamentals, in the form of frameworks, definitions, standards, then the members cannot carry out the intended work. At semantic boundaries, members are required to specify and understand their differences and interdependencies across specific boundaries. An interpretation process or translation between the members is carried out with the use of objects, models and maps. At pragmatic boundaries, a facilitation process is necessary where members can together transform their domain or community specific knowledge. Chu & Lee (2014) claims that the three levels, from the bottom up, involve information processing, cultural and political perspectives.

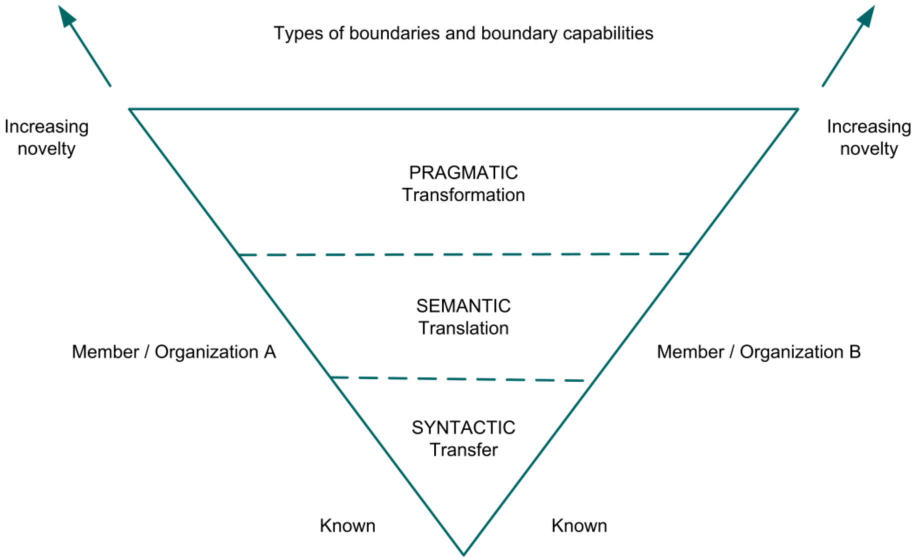

FIGURE 3-15. THREE CATEGORIES OF KNOWLEDGE BOUNDARIES (CARLILE 2004)

Two elements are cited as important for spanning boundaries: boundary objects and knowledge brokers. Boundary objects (BOs) were first introduced as a concept by Star & Griesemer (1989) and defined as:

> *"Objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual site use. These objects may be abstract or concrete. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is a key process in developing and maintaining coherence across intersecting social worlds"* (p.393).

Boland & Tenkasi (1995) speak of boundary objects, reflexivity and perspective taking:

> *"Once a visible representation of an individual's knowledge is made available for analysis and communication, it becomes a boundary object and provides a basis for perspective taking"* (p.362).

Wenger (1998) defines BOs as objects that serve to coordinate perspectives of different members and products of reification. BOs have information carrying "abilities" for knowledge transfer as well as the potential to develop and maintain coherence within or between several CoP (Bowker & Star 2000). They can represent tangible artefacts or carry explicit or implicit information or meanings while also possessing interpretive flexibility (Bijker et al. 1987). According to Wenger (1998), BOs have four characteristics: modularity, where one member can address one part of a BO and it can still be coherent to all; abstraction, where BOs possess commonness after the deletion of particularities associated with each group that is involved; accommodation, where BOs can be modified to various activities in different communities; and standardization, where information contained within BOs is predefined so members of different communities know how to manage it.

BOs can thus be an effective way to represent the various interests of stakeholders from different domains. BOs help to foster collaboration but as Wenger (1998) cautions of the dangers related to reification, Swan et al. (2007) also warn how BOs can inhibit knowledge sharing across communities. Several authors provide descriptions of the types of BOs as described in Vakkayil (2014). Examples include discourses and vocabulary, legislation, corporate standards, prototypes, design drawings, or ecodesign tools. Wenger (2000b) presents three categories of BOs: artefacts representing tools, documents, models shared by CoP; discourses which include a common language that can be shared across CoP; and processes that can be shared such as routines or procedures which facilitate coordination of and between CoPs. Carlile (2002) typifies BOs and differentiates between three kinds which link back to his conceptualization in Figure 3-15: repositories that offer a shared reference for data, labels or measurements such as cost databases, parts libraries or CAD databases; standardized forms and methods which represents a shared problem solving format such as mental maps, sketches, prototypes or computer simulations; and objects, models and maps which are denoted as the only BOs that support knowledge transformation. A summary of these types of BOs and how they are paired with syntactic, semantic and pragmatic knowledge boundaries are provided in Table 3-4.

TABLE 3-4. TYPE OF KNOWLEDGE BOUNDARY, CATEGORY AND CHARACTERISTICS OF BOUNDARY OBJECTS (CARLILE 2002, p.453)

Boundary type	Category of boundary object	Characteristics of boundary object
Syntactic	Repositories	Representing
Semantic	Standardized forms and methods	Representing and learning
Pragmatic	Objects, models and maps	Representing, learning and transforming

The second element for supporting knowledge integration across boundaries is a broker, otherwise known as boundary mediator, carrier of knowledge (Maaninen-Olsson et al. 2006) or community leaders, champions and facilitators (Wenger et al. 2002). Wenger (1998) describes brokering as the act of introducing elements of one practice into another. Brokers thereby create bridges across practices. In this research context, a broker is someone who facilitates positive environmental change by encouraging different people, functions or companies to communicate and cooperate. However, multi-membership does not necessarily imply brokering, which is an intentional process where members:

> *"Make new connections across communities of practice, enable coordination, and – if they are good brokers – open new possibilities for meaning. [...] The job of brokering is complex. It involves processes of translation, coordination, and alignment between perspectives. It requires enough legitimacy to influence the development of a practice, mobilize attending, and address conflicting interests. It also requires the ability to link practices by facilitating transactions between them, and to cause learning by introducing into a practice elements of another"* (Wenger 1998, p.109).

Wenger (1998) claims that certain individuals thrive on being brokers and these members are typically positioned at the communities' boundaries, rather than their core. He uses the term trajectory to describe the temporal nature of member's identity as it is socially constructed over time through different social contexts. There are a number of different types of trajectories, which include: peripheral trajectories: members who never become full community participants but they can still marginally contribute; inbound trajectories: newcomers with the prospect of becoming full members; insider trajectories: core members that are consistently seeking to renegotiate community practices and their individual identities; boundary trajectories: brokering members who span the boundaries and link different communities' practices; and outbound trajectories: members in the process of leaving a specific practice community in search of a new one.

I analyse knowledge boundaries between environmental and product development functions in SWP and assess how boundary objects and brokers can facilitate the integration and practice of ecodesign in my publication in Chapter 8.

3.3.3. CULTIVATING PRACTICE COMMUNITIES

Wenger & Snyder (2000) highlight the organizational value of CoP:

> *"CoP can drive strategy, generate new lines of business, solve problems, promote the spread of best practices, develop people's professional skills, and help companies recruit and maintain talent"* (p.140).

In the early 1990s there was a growing interest to use CoP concepts in business and organizational studies (Brown & Duguid 1991; Lave & Wenger 1990; Orr 1996). CoP concepts remain prominent in management literature as Hernáez & Campos (2011) discovered in their more recent study. Despite interest in literature, only few organizations have adopted the concept in practice. Wenger & Snyder (2000) suggest three reasons management have difficulties seeing the value of CoP: first, the term is relatively new to the business world; second, few companies have applied the concept to which they can inspire others; and third, it is not easy to establish and sustain CoP within current business environments. Cox (2005) also contends with the last point, arguing that today's organizations and working environments inhibit collective sense making, leading to fragmented tasks and silo thinking.

There is an ongoing debate whether CoP naturally emerge or if they're intentionally created. Murillo (2011, p.7) provides an elaborate review of these contrasting views. For those in the former group, CoP are emergent, informal and self-organising. They set their own learning agendas and operate beyond management control. For those in the latter group, CoP are seen as hidden resources that should be identified and supported by management by seeding and nurturing the environments in which they exist. They focus on pursuing knowledge initiatives that have strategic value for the organisation.

This research is aligned with the views of Wenger & Snyder (2000) and Wenger et al. (2002); although CoP are often informal and self-organizing, they can be intentionally nurtured and cultivated. Wenger (2000a) identifies three ways manages can recognize a CoP and sustain it: identify potential communities of practice that will enhance the company's strategic capabilities; provide the infrastructure that will support such communities and enable them to apply their expertise effectively; and use non-traditional methods to assess the value of the company's communities of practice (p.144). Wenger (2004) informs:

> *"the most successful communities have always combined bottom-up enthusiasm and initiative from members with top-down encouragement from the organization"* (p.6).

Regardless how a community is created, most CoP begin as loose networks and expand their membership, depth of knowledge and practices over time. Eventually, a community extends where active stewardship and knowledge transformation is commonplace (Wenger et al. 2002). Figure 3-16 highlights five stages of community development that include: potential, coalescing, maturing, stewardship and transformation.

In the early stages (potential to maturing), members of a CoP are focused on defining its scope, establishing its value in relation to the company, recruiting and aligning members, finding ways to engage and develop trusting relationships. In these stages many things are open for negotiation when building connections and seeking legitimacy. While in the later stages (maturing to transformation), the members of a CoP are focused on institutionalizing the community in the company and finding relevance in other domains, managing boundaries to ensure focus, establishing ownership and routines, and sustaining momentum. In these stages the community tends to focus on its own enterprise and establish routine practices. This makes it difficult for introducing new members and for changing existing practices. Core community members tend to overlook the value of boundary practices and the brokers themselves who often function outside of the core group, or at the periphery.

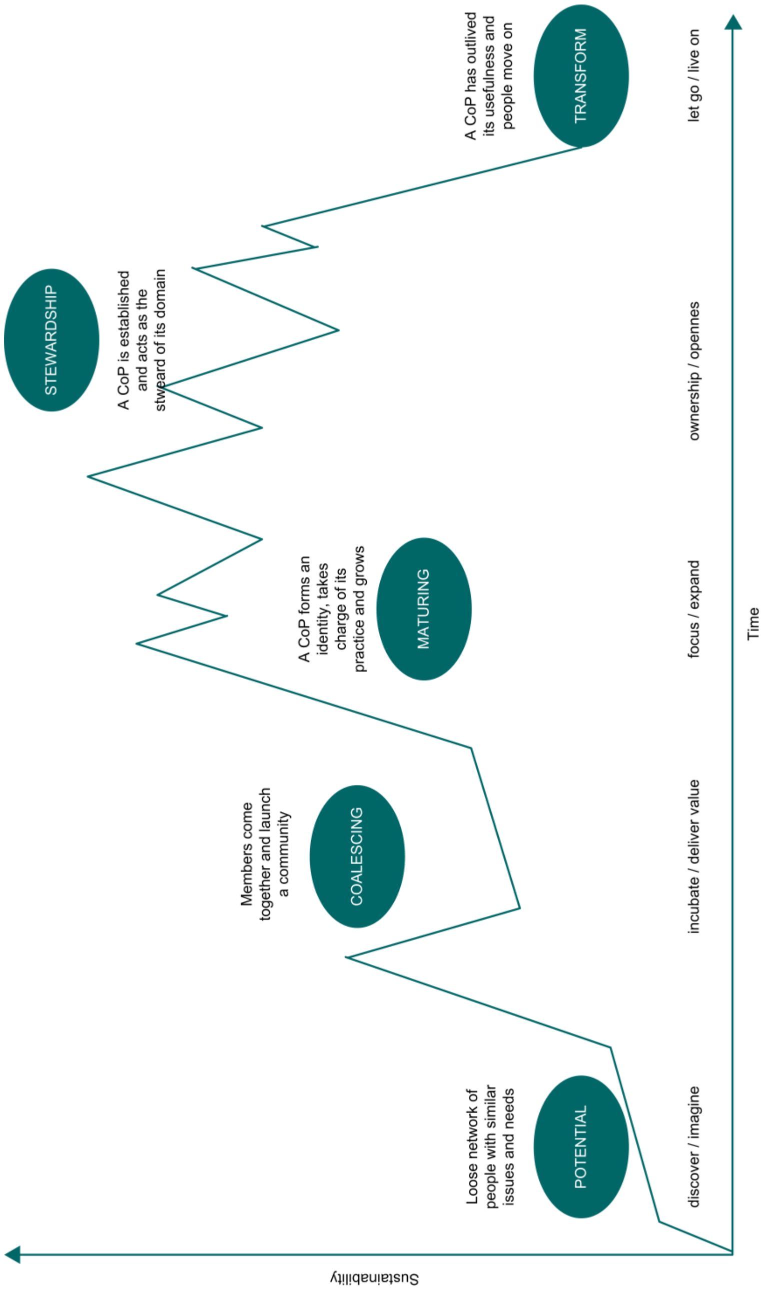

FIGURE 3-16. STAGES OF COMMUNITY DEVELOPMENT (WENGER ET AL. 2002)

A community's ability to be sustained depends on the engagement of its members (internal leadership) and the environment in which it exists. For example, if the practice is valued, if sufficient time and resources are allocated to supporting community activities and if participation is encouraged and barriers are removed (Wenger et al. 2002). Senge's (1990) highlights five components that are necessary for a learning organization: systems thinking where organizational functions are aware of their interdependences with one another and everything works in unity as one system; shared vision which is not imposed by the leadership and can be translated at every level so it is recognized, create energy for learning and is owned as a shared vision; personal mastery where people acknowledge one another's distinctive abilities and continue to expand their own as a commitment to the process of learning; mental models (reified BOs) shared by all members giving the ability to negotiate new and unwanted values; and team learning where the accumulation of individual knowledge can be shared with other members to become the team's knowledge (Figure 3-17).

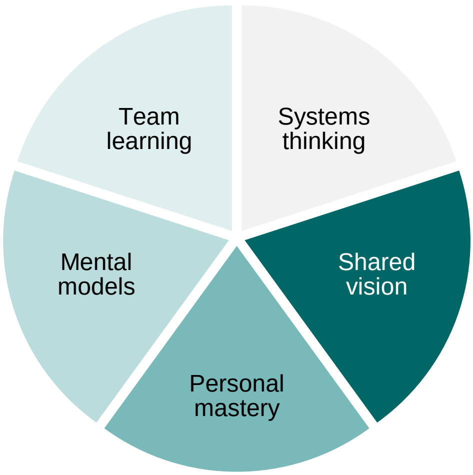

FIGURE 3-17. FIVE COMPONENTS OF A LEARNING ORGANIZATION (SENGE 1990)

Wenger's and others' work on CoP has inspired my research approach and directed my focus to evaluate: current environmental and product design practices; the prospective ecodesign practices; the use of tools to facilitate the negotiation of meaning around ecodesign between environmental and product design communities; and my role as a broker to mediate between these two communities. In my design based research process, my goal is to co-develop new and meaningful ways with the two communities to promote the formation of new participatory modes and the creation and use of ecodesign tools. The ultimate goal is to instil learning opportunities for both communities.

In this research context there are well established environmental and product development communities which could be positioned in the stewardship stage. Wenger et al. (2002) caution of underlying tensions in this stage that relate to ownership and openness. Both communities have established a strong membership and level of expertise. A strong sense of ownership naturally follows with this, where the members take pride in the ideas, artefacts and practices they engage with. However, their boundary spanning with one another was limited at the onset of this study. Based on this, the community's level of openness could potentially affect the integration of ecodesign. Based on the business objectives 1.1.1, the environmental community was interested in establishing new relations with the product development community. However, there was uncertainty whether the product development community would be open and accepting of the environmental members' ideas, redefine their boundaries and involve the environmental broker as a boundary or inbound member. Alternatively, they could be resistant and the environmental community broker would remain peripheral to that community.

4 ECODESIGN DRIVERS AND BARRIERS

This chapter contains the following article:

REVIEW OF FACTORS INFLUENCING ECODESIGN AND AN ORGANIZATIONAL DEVELOPMENT FRAMEWORK TO SUPPORT IMPLEMENTATION

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ABSTRACT

Significant organizational change is required for companies to extend beyond their traditional, firm based environmental activities, to more value chain and systems based sustainability activities such as ecodesign and circular economy. Ecodesign is based on three decades of research and industry practice and has a number of reported benefits. However, industrial integration is cited as being weak due a number of barriers. Several researchers associate implementation challenges with a lack of attention to the "soft" side of ecodesign or the social practices and organisational structures necessary for successful change. In this research, successful change and environmental improvements are a result of reflective learning in communities of practices. In the first part of this article, we empirically analyse what the drivers and barriers are for ecodesign and how these might change over time. We also consider what measures are used to overcome the challenges. Drivers and barriers are evaluated through a literature review and semi-structured interviews with seven multinational companies. The dominant drivers include legislation, customers, employees and partnerships while the dominant barriers relate to leadership (in terms of management support and employee ownership), business relevance/value and communication. In the second part of the article, an organizational development framework is presented for ecodesign implementation that has a particular emphasis on learning. The framework encourages practice communities which generate sense making and knowledge in order to advance ecodesign in companies.

KEYWORDS

Product oriented environmental management; drivers and barriers; literature review; organisational change; organizational learning; communities of practice.

4.1. INTRODUCTION

More than ever before, businesses are faced with a mixture of environmental, social, market and technological trends. Such trends can threaten business operations because a company chooses either to reactively respond or do nothing altogether. Conversely, trends can enhance a company's operations and transform its value chain because the company anticipates the operational effects and proactively responds (Loorbach & Wijsman 2013). Companies operating in sectors e.g. food, mobility, power generation and construction sectors where global megatrends such as climate change and resource depletion are likely to directly affect their business models are especially in the interest of adopting corporate sustainability practices (Grin et al. 2010; UNEP 2010b).

Corporate sustainability has been transforming the competitive landscape and prompting companies to rethink aspects related to their products, technologies, processes and overall business models. Companies adopting more strategic approaches are becoming aware of both the need for, and the benefits of, transitioning from firm based environmental activities such as cleaner production towards broader value chain and systems based activities such as ecodesign, sustainable supply chain management and circular economy (Adams et al. 2012; Ahi & Searcy 2015; Loorbach et al. 2009). Examples include the more than 300,000 certifications to ISO 14001 in 171 countries globally (ISO 2016), the 8,041 companies in 170 countries that have signed the UN Global Compact (UNGC 2015), the 164 manufacturers, retailers and suppliers participating in The Sustainability Consortium (TSC) for greening consumer goods, as well as those companies collaborating in The Circular Economy 100 (CE100) for closed loop business models.

As reported by Pigosso et al. (2015) and Adams et al. (2012), companies have especially gone beyond their own company borders the last five years. This expansion of scope is a difficult task because companies must apply wider life cycle thinking, possess strategic foresight and engage with more diverse stakeholders. Organizational changes are thus essential within the company, throughout the value chain and across larger societal networks and domains. Within the company, organizational changes are necessary at strategic, tactical and operational levels (Kuhndt 2004) and at the individual level of managers and employees.

Ecodesign is defined by ISO 14006:2011 as the systematic integration of environmental aspects in product design and development in order to reduce the adverse environmental impacts associated with a product across its life cycle (ISO 2011). It correlates with the twelfth UN Sustainable Development Goal for responsible consumption and production. Companies can apply ecodesign strategies to optimize their use of resources and innovate the way their products and services are perceived and thus, potentially contribute to leaner operations, a more circular economy and sustainable society.

Based on three decades of research and industry practice, ecodesign is considered a mature subject (Brezet & van Hemel 1997; Pigosso et al. 2015). A number of guides and standards have been developed to facilitate integration in companies (Brezet & van Hemel 1997; ISO 2002, 2011; McAloone & Bey 2000; Tischner et al. 2000). Drivers, benefits and success factors related to ecodesign have been studied but to a lesser extent in recent years (Johansson 2002; Plouffe et al. 2011). Despite this, industrial barriers to implementation remain prevalent and continue to be the focus of investigation (Bey et al. 2013; Dekoninck et al. 2016; Rossi et al. 2016).

A number of important works correlate industrial barriers to a lack of contributions from the social science and organizational disciplines, otherwise known as the "soft" side of ecodesign (Boks 2006; Brones et al. 2016; Johannson et al. 2007; Skelton et al. 2016). Stone (2006a) for example, stresses the importance of taking a humanistic approach (rather than mechanistic) by emphasizing the role people have in generating change. Strategies, procedures and tools in and of themselves do not generate the necessary change. Yet, Stone (2006b) warns that environmental change in companies is heavily based on a number of false assumptions e.g. the "presence" of a "motivated" change agent; "voluntary" commitment from top management; employee commitment "as a result of" top management commitment; "effortless" capacity building and "collaboration" amongst employees; the "presence" of skills, and "ease" to overcome difficulties; a "mechanistic" and "sequential" way of achieving continuous improvements. Change often fails due to a lack of organizational culture and social structures that are essential for reflective learning and environmental improvements (Stone 2006b).

Pigosso et al. (2015) identify nine trends for future ecodesign research, where the eighth concerns expanding from the technical arena to an organizational arena. We believe this trend should be elevated in importance considering the previous studies on industrial barriers and the predominant focus on technical aspects or the "hard" side of ecodesign. In response to this, our research addresses a number of identified research gaps:

Dekoninck et al. (2016) indicate a lack of analyses around the challenges companies face, as well as a shortage of empirical research on industrial practices, particularly by companies who have a track record in implementing ecodesign (gap 1). Further, Johansson et al. (2007) inform that few studies have addressed how different mechanisms may reduce these challenges (gap 2). In the first part of this research we empirically analyse what the drivers and barriers are for ecodesign and how these might change over time (goal 1 in response to gap 1). We also consider what measures are used to overcome the challenges (goal 2 in response to gap 2).

Furthermore, Boks (2006) and others calls for a focus on the "soft" side of ecodesign (gap 3). In the second part of this research we aim to complement and deepen discussions on the human mechanisms advocated for implementation. In trying to understand how companies generate the organizational change necessary for ecodesign implementation (goal 3 in response to gap 3), we present an organizational development conceptual framework for ecodesign implementation that has a particular emphasis on learning.

The paper is organized in six sections: in section 4.2, the research design and applied methods are described. A synthesis of ecodesign drivers and barriers in literature are presented in section 4.3, while section 4.4 provides an analysis of company responses regarding these motivations and challenges against literature, giving particular attention to how influencing factors change over time in the companies. In section 4.5 an organizational development conceptual framework is presented that was derived from a literature review about learning and organizational change. In section 4.6, the research questions are answered and the research implications are discussed, which concludes the paper.

4.2. RESEARCH METHODS

The research is presented in three parts: (1) a literature review is compiled about the factors influencing ecodesign e.g. drivers and barriers; (2) a series of semi-structured interviews are conducted with seven multi-national companies (MNCs) about how their influencing factors change over time; (3) a literature review is compiled about learning and organizational change. This contributes to the development of a conceptual framework for organizational development to support implementation. The framework emphasizes organizational change by social learning in communities.

4.2.1. LITERATURE REVIEW

A systematic literature review was the first step conducted in this research. The purpose was to gain an understanding of the drivers and barriers to ecodesign and to act as guidance for the second step involving interviews. The electronic database selected for review was ScienceDirect and a number of keywords were iteratively searched (Table 4-1). A shortcoming of the electronic search was that the database returned a number of works from academic journals and e-books but failed to include some of the classic guidebooks (Tischner et al. 2000) and reports (UNEP 1997, 2007).

TABLE 4-1. KEYWORDS USED IN THE SYSTEMATIC LITERATURE REVIEW OF THE INFLUENCING FACTORS OF ECODESIGN

Keywords			
Drivers	Barriers	Ecodesign	Environmental (product) design
Motivations	Challenges	Eco-design	Sustainable (product) design
Incentives	Obstacles	Green design	Green (product) design
Influences	Difficulties	Design for environment	Product oriented environmental management (POEM)
Success factors	Adoption	Design for sustainability	

4.2.2. SEMI-STRUCTURED INTERVIEWS

The literature review revealed that most former studies distributed questionnaires to large firm samples or synthesized preceding studies. Few authors used interview methods (Erlandsson & Tillman 2009; O'Hare 2010; van Hemel & Cramer 2002), so our intention was to select a smaller number of companies who had varying degrees of ecodesign experience and subsequently use a qualitative case-based approach (Yin 2009) with semi-structured interviews (Kvale 1983, 1996). A small sample size and semi-structured interviews, in contrast to questionnaires, provided more comprehensive details. Furthermore, the one-on-one format provided a setting to discuss potentially, company sensitive information in order to gain a deeper understanding of their specific organizational contexts. Relations between respondent and researcher also provided both the means to clarify if a question or response was misunderstood.

Deutz et al. (2013) point to a lack of broad based ecodesign studies that go beyond individual examples to provide wider comparison of practices across industries. In response to this, a total of seven MNCs representing a variety of industries were selected for interviews. Company and interviewee selection was based on three aspects: (1) Pre-existing professional relations between the researchers and company representatives as this encouraged a higher participation rate and access to information; (2) Historical and current experiences with ecodesign. The analysis was not limited to companies who have worked with ecodesign for the same number of years, as the number of years is not linked to the success of ecodesign, which was verified by respondents; (3) Market presence in the respective industries and sectoral variety of the companies. Sectoral variety enabled more open discussions because competitive elements were minimized and also qualified generalizability.

All of the selected companies participate in both product development and manufacturing activities and constitute a mix of business-to-business (B2B) and business-to-customer (B2C) transactions. They range in size from 10,000 to 160,000 employees and all have headquarters in Europe. One interviewee was selected per company who sat within an environmental, sustainability or R&D role. Additional characteristics about the companies and interviewees are outlined in Table 4-2, where companies are assigned letters A-G to ensure anonymity. The taxonomy of industrial sectors is based on the Global Industry Classification Standard (GICS).

Broad based questions were used with the aim of attaining spontaneous answers about drivers and barriers and their degree of relative importance to ecodesign (Kvale 1996). This is in contrast to questionnaires where the predefined response options can potentially influence respondents' answers. The questions addressed the context of the companies' operations and their ecodesign practices, including insights about the drivers, barriers and countermeasures for overcoming the identified challenges. The questions also involved a time element to determine if and how drivers and barriers change over time. Ecodesign during initial implementation and current practice was assessed but future strategies that were not yet implemented were omitted from the discussions. An evolutionary approach was selected because the literature review revealed that only one source considered both initiating and sustaining drivers (Bey et al. 2013). This is reinforced by Dekoninck et al. (2016) who claim that the majority of studies report on the start-up of ecodesign practices but significantly less on the ongoing experiences.

The interviews were an average length of one hour and were transcribed to enable analysis against initial goals. A review of the selected companies' external communication supplemented the interview analysis e.g. publicly available websites and material supplied by the respondents.

Firm	Sector	Industry	HQ location	No. employees	Business type	Initial ecodesign	Interviewee title Function
A	Consumer staples	Food, personal & household items	UK	160,000	Public (B2C)	Mid 1980s	Science and Technology Lead, Sustainability function
B	Industrial	Capital goods (power automation)	CH	130,000	Public (B2B)	1992	Senior Principle Scientist, R&D function (corporate)
C	Consumer discretionary	Consumer durables	NL	115,000	Public (B2B, B2C)	1993	Senior Environmental Advisor, R&D function (market unit)
D	Industrial	Capital goods (liquid transport)	DK	20,000	Private (B2B, B2C)	1993	Senior Sustainability Specialist, Environmental function (corporate)
E	Consumer discretionary	Automobiles and components	SE	100,000	Public (B2B, B2C)	1994	Regulatory Expert, Environmental function (corporate)
F	Healthcare	Equipment and services	DK	10,000	Public (B2B)	2002	Senior EHS Specialist, EHS function (corporate)
G	Industrial	Capital goods (power generation)	DE	10,000	Public (B2B)	2011	Senior Environmental Specialist, EHS function (corporate)
A	Consumer staples	Food, personal & household items	UK	160,000	Public (B2C)	Mid 1980s	Science and Technology Lead, Sustainability function

TABLE 4-2.OVERVIEW OF THE KEY CHARACTERISTICS OF THE COMPANIES AND INTERVIEWEES

4.2.3. CONCEPTUAL FRAMEWORK

A secondary literature review on organizational development theory was compiled. The purpose was to develop a conceptual framework that addressed organizational change from a social learning perspective to support ecodesign implementation. The review followed an identical process as the one listed in 4.2.1 and the key references are provided throughout section 4.5 (cf. Table 3-1).

4.3. LITERATURE REVIEW

Erlandsson & Tillman (2009) suggested that “influencing factors” can constitute both drivers and barriers. The characterization of ecodesign drivers and barriers continue to be a focus of ecodesign research (Dekoninck et al. 2016; Pigosso et al. 2013; Rossi et al. 2016). Most authors investigated both influencing factors but some focused only on the motivations (Pigosso et al. 2013) or the challenges to ecodesign implementation (Dekoninck et al. 2016; Rossi et al. 2016). The following two sub-sections present some of the common drivers (4.3.1) and barriers (4.3.2) as reported by literature.

4.3.1. ECODESIGN DRIVERS

Drivers represent the internal or external motivational factors for initiating or continuing ecodesign. People, trends, structures or events can influence drivers. Ecodesign drivers are summarized in Table 4-3 and are organized by both motivating stakeholders and associated benefits. In Table 4-4 drivers that have been classified as either internal or external are also listed. We make this differentiation because some studies indicate the importance of certain drivers e.g. van Hemel & Cramer (2002) concluded that internal drivers are stronger than external drivers for small and medium-sized enterprises. While van Hemel & Cramer (2002) indicated that ecodesign is most successful when supported by combination of internal and external drivers. Some authors not only identified but also ranked the importance of drivers (Murillo-Luna et al. 2011; O'Hare 2010).

According to Banerjee (2001) a company’s response to ecodesign drivers is dependent on the managerial perception of risks and opportunities, and can be classified as either reactive or proactive. Further, Bey et al. (2013) referred to two types of drivers: (1) those that “trigger” ecodesign, and (2) those that “sustain” it.

TABLE 4-3. SUMMARY OF DRIVERS BASED ON LITERATURE ORGANIZED BY STAKEHOLDERS AND BENEFITS

Drivers	Authors
Stakeholders	
Authorities, politicians, government i.e. Legislation, market instruments, subsidies	Ammenberg & Sundin (2005); Bey et al. (2013); Johansson & Sundin (2014); Mortimer (2010); O'Hare (2010); Reyes et al. (2006); Zutshi & Sohal (2004)
Banks, insurance companies	Ammenberg & Sundin (2005)
Certification bodies, standardization organizations, auditors	Ammenberg & Sundin (2005)
Competitors	Ammenberg & Sundin (2005)
Customers	Ammenberg & Sundin (2005); Bey et al. (2013); Johansson & Sundin (2014); Mortimer (2010); O'Hare (2010); Reyes et al. (2006)
Employees	Bey et al. (2013); González-Benito & González-Benito (2006); Mortimer (2010); O'Hare (2010)
Industrial sector, industry associations	González-Benito & González-Benito (2006); Reyes et al. (2006)
Management	Bey et al. (2013); González-Benito & González-Benito (2006); O'Hare (2010); Reyes et al. (2006)
Media	Ammenberg & Sundin (2005)
Shareholders	Ammenberg & Sundin (2005); O'Hare (2010); Reyes et al. (2006)
Stakeholders	Ammenberg & Sundin (2005); Bey et al. (2013); González-Benito & González-Benito (2006); O'Hare (2010); Reyes et al. (2006)
Benefits	
Advances in innovation, creativity, staff skills	Bey et al. (2013); Mortimer (2010); Plouffe et al. (2011)
Competitive advantage, strategic proactivity	Bey et al. (2013); González-Benito & González-Benito (2006); Johansson & Sundin (2014); Mortimer (2010);O'Hare (2010); Plouffe et al. (2011)

Compliance	Veshagh et al. (2012)
Cost reduction	Johansson & Sundin (2014); Mortimer (2010); Plouffe et al. (2011); Reyes et al. (2006); Veshagh et al. (2012)
Employee satisfaction	Bey et al. (2013); Plouffe et al. (2011)
Enhanced brand image, credibility	Bey et al. (2013); Johansson & Sundin (2014); Mortimer (2010); O'Hare (2010); Plouffe et al. (2011); Reyes et al. (2006); Veshagh et al. (2012); Zutshi & Sohal (2004)
Improved relations	Plouffe et al. (2011)
Process improvements i.e. systematic approach, life cycle thinking	Plouffe et al. (2011)
Product improvements i.e. quality, environmental impact	Johansson & Sundin (2014); O'Hare (2010)
Risk aversion/management	Short et al. (2012); Veshagh et al. (2012); Zutshi & Sohal (2004)

TABLE 4-4. SUMMARY OF INTERNAL AND EXTERNAL DRIVERS BASED ON GOSLING ET AL. (2014), ERLANDSSON & TILLMAN (2009), SHORT ET AL. (2012), VAN HEMEL & CRAMER (2002)

External drivers	Internal drivers
Authorities, politicians, government i.e. legislation, permits, green public procurement	Advances in innovation, creativity
Certification bodies, standardization organizations, auditors	Altruism, proactivity
Competitors	Assigned responsibilities i.e. performance management
Customers	Brand image
Industrial sector, industry associations	Company features i.e. position, size, design, strategy
Media i.e. documentaries, campaigns	Competitive advantage
NGOs i.e. ecolabels, consumer guides	Cost reduction
Public i.e. blogs, forums	Employees i.e. demand, motivation, capabilities
Risk aversion, risk management	Management commitment i.e. resources
Shareholders	Organizational culture and strategy
Suppliers	Product improvements i.e. quality, environmental impact
University, research institutes	Requirement from corporate or parent organization

4.3.2. ECODESIGN BARRIERS

Barriers represent the internal or external challenges companies face when initiating or continuing ecodesign. They can either hinder ecodesign or prevent its integration and practice all together (Murillo-Luna et al. 2011; van Hemel & Cramer 2002). Like drivers, people, trends, structures or events can influence the presence and severity of a barrier. Murillo-Luna et al. (2011) reported that barriers to environmental change were widely studied in the 1990s while Dekoninck et al. (2016) contest that the characterisation of barriers and challenges is less complete today.

Ecodesign barriers are summarized in Table 4-5 and are categorized in a series of six groups. Following in Table 4-6, some authors not only identified but also ranked the importance and frequency of barriers (Bey et al. 2013; Dekoninck et al. 2016; Short et al. 2012).

TABLE 4-5.SUMMARY OF BARRIERS BASED ON LITERATURE CATEGORIZED INTO SIX GROUPS

Barriers	Authors
Leadership	
Cultural	O'Hare (2010); Verhulst et al. (2007a)
Time resources	Ammenberg & Sundin (2005); Dekoninck et al. (2016); O'Hare (2010); Reyes et al. (2006)
Investment costs	van Hemel & Cramer (2002); Veshagh et al. (2012)
Lack of assigned responsibility	Reyes et al. (2006); van Hemel & Cramer (2002); Verhulst et al. (2007a)
Lack of a business case, cost/benefit	Dekoninck et al. (2016); Mortimer (2010)
Lack of management support	Johansson & Sundin (2014); O'Hare (2010); Reyes et al. (2006)
Lack of broad-level commitment e.g. strategies, policies	Ammenberg & Sundin (2005); Dekoninck et al. (2016); Erlandsson & Tillman (2009); Mortimer (2010); O'Hare (2010); Reyes et al. (2006); Verhulst et al. (2007a)
Resistance to change	Mortimer (2010); Reyes et al. (2006)

Stakeholder collaboration	
Supply chain complexities e.g. supplier capabilities	Erlandsson & Tillman (2009); González-Benito & González-Benito (2006); Mortimer (2010)
Stakeholder conflicts e.g. cooperation	Dekoninck et al. (2016); Erlandsson & Tillman (2009); Mortimer (2010); O'Hare (2010); Reyes et al. (2006); Verhulst et al. (2007a)
Lack of customer requirements	Erlandsson & Tillman (2009); Mortimer (2010); O'Hare (2010); Reyes et al. (2006); van Hemel & Cramer (2002); Veshagh et al. (2012)
Lack of legislation	Mortimer (2010); O'Hare (2010)
Lack of, or weak, external drivers	Ammenberg & Sundin (2005); Erlandsson & Tillman (2009)
Individual risks	Short et al. (2012)
Communication and knowledge	
Insufficient knowledge, capabilities	Ammenberg & Sundin (2005); Dekoninck et al. (2016); Johansson & Sundin (2014); Murillo-Luna et al. (2011); O'Hare (2010); Reyes et al. (2006)
Lack of methodological capabilities, training, experience	Dekoninck et al. (2016); Mortimer (2010); Reyes et al. (2006)
Process integration	
Process integration	Ammenberg & Sundin (2005); Dekoninck et al. (2016); O'Hare (2010)
Organizational design structure	Dekoninck et al. (2016); Erlandsson & Tillman (2009); Verhulst et al. (2007a)
Weak enforcement framework	Erlandsson & Tillman (2009)
Tool oriented	
High acquirement costs	Reyes et al. (2006)
Appropriate tools or methods e.g. variety, specificity, complexity	Dekoninck et al. (2016); Johansson & Sundin (2014); Mortimer (2010); Reyes et al. (2006); Rossi et al. (2016)

Lack of specifications or standards	Rossi et al. (2016)
Market and customer oriented barriers specific to tools	Rossi et al. (2016)
Sufficient resources e.g. time, knowledge	Rossi et al. (2016)
Product improvement	
Commercial disadvantages	Reyes et al. (2006); van Hemel & Cramer (2002)
Conflicts between functional and environmental options	Reyes et al. (2006); O'Hare (2010); van Hemel & Cramer (2002)
Doubt of environmental benefits, product impacts	Reyes et al. (2006); van Hemel & Cramer (2002)
No alternatives available	van Hemel & Cramer (2002)
No innovation opportunities	van Hemel & Cramer (2002)

TABLE 4-6. BARRIERS RANKED IN IMPORTANCE OR FREQUENCY BY LITERATURE

Barriers by author	
Bey et al. (2013)	
Insufficient information or knowledge	Balancing trade-offs
Insufficient resources i.e. time	Lack of cooperation or collaboration
No alternatives available i.e. materials or technologies	Maintaining momentum, continuous improvements
Tools i.e. complexity	Lack of policy or strategy
Dekoninck et al. (2016)	
Integration with new product development	Problems applying existing tools
External collaboration	Managing requirements
Developing a long term strategy	Building the business case
New knowledge and expertise	Resource allocation
Internal collaboration	New types of data required
Finding the right tool	Organizational design and structure
Short et al. (2012)	
Lack of time or low priority	Lack of cooperation or collaboration
Changing customer requirements	Poor understanding of customer needs
Timeliness receiving requirements	Poor project management
Insufficient information or knowledge	Lack of a structured and understood NPD process
Technology uncertainty	Lack of management support

4.4. INTERVIEW RESPONSES

In this section, we present the drivers (4.4.1) and barriers (4.4.2) to ecodesign based on interview responses with seven MNCs. The responses are synthesized and compared with the literature review from section 4.3.

4.4.1. DRIVERS MOTIVATING ECODESIGN PRACTICE

This research differentiates between ecodesign drivers in initial implementation and current practice; initial drivers are defined as motivating factors that lead companies to engage with ecodesign for the first time, while current drivers depict the current (at the time of the interviews in 2013) motivating factors that lead companies to continue practising ecodesign after initial implementation. The average date for initial implementation was 1996, representing an average span of 17 years between initial implementation and current practice. A comparison between internal and external drivers during both time periods is provided in Table 4-7.

TABLE 4-7. COMPARISON BETWEEN INTERNAL AND EXTERNAL DRIVERS DURING INITIAL AND CURRENT (2013) ECODESIGN PRACTICE

Drivers	Initial implementation	Current practice
External		
Legislation	C,F	D,E,F
Customers		C,D,E,G
Partnerships	B,D,G	
NGOs	A,C,	
Internal		
Management	D	A,B,C
Group of employees	B	B,F,G
Single employee	E,G	
Corporate requirements	G	

Based on interview responses in Table 4-7, the following can be summarized:

- Four external and four internal drivers were identified by respondents.
- External drivers were referenced 14 times and internal drivers were cited 11 times.
- Respondents referenced drivers 12 times in initial implementation and 13 times in current practice.
- Legislation; customers; and management were cited as the three most significant drivers amongst the companies, based on response numbers. Legislation was referenced five times by four companies. Customers and management were also equally referenced four times by four companies.
- In initial implementation six of seven companies made seven references to external drivers, while four of seven companies made five references to internal drivers.
- In current practice five of seven companies made seven references to external drivers, while five of seven companies made six references to internal drivers.
- In initial implementation, partnerships i.e. with industry associations, ministries or universities were a predominant driver referenced three times. Legislation, NGOs and a single employee were also equally referenced two times. Partnerships were the strongest external driver, while a single employee was the strongest internal driver.
- In current practice, customers were referenced four times. Legislation, management and group employees were also equally referenced three times; Customers was the strongest external driver, while management and group employees were the strongest internal drivers.
- Response variety was higher in initial implementation compared to current practice.

Van Hemel & Cramer's (2002) research with small and medium sized enterprises (SMEs) concluded that internal drivers were a stronger ecodesign force than external stimuli. Conversely, this research finds that companies are slightly more externally driven (14 to 11 references) in both the initial (seven to five) and current (seven to six) phases of ecodesign. It also finds that motivational orientation shifts as companies continue to practice ecodesign. The number of referenced drivers increased 12 to 13 between initial and current practice. Over time, two companies referenced an additional driver (E and F), while company G referenced one less driver. Further, only two drivers (group of employees and legislation) were consistent for two of the companies (B and F). The other companies experienced an overall change in drivers across time.

The drivers reported reflected motivations from specific stakeholder groups. Both González-Benito & González-Benito (2006) and Erlandsson & Tillman (2009) defined stakeholders as important influencing actors of environmental pro-activity. However, other authors found company or product factors were also influencers of ecodesign e.g. the product and its impact, company size, position in the product chain, geographical location, profitability, etc. (Ammenberg & Sundin 2005; Erlandsson & Tillman 2009; Gosling et al. 2014). Other sources identified additional drivers that were not intuitively listed by the companies interviewed such as economic benefits e.g. reduced costs or increased revenues (Ammenberg & Sundin 2005; Erlandsson & Tillman 2009; ISO 14006 2011; Johansson & Sundin 2014; Plouffe et al. 2011; Reyes et al. 2006; Short et al. 2012; van Hemel & Cramer 2002), market or competitor advantages (Johansson & Sundin 2014; Lee & Kim 2011; van Hemel & Cramer 2002), improved company image or brand value (Bey et al. 2013; ISO 14006 2011; van Hemel & Cramer 2002), improvements to innovation or increased product quality (van Hemel & Cramer 2002), improved cooperation across departments or throughout the supply chain (Ammenberg & Sundin 2005), enhanced employee motivation or learning (Ammenberg & Sundin 2005; ISO 14006 2011). None of these non-stakeholder specific drivers were mentioned by respondents. One potential reason is due to the broad based interview questions which may have differed if respondents were presented with a list of possible drivers.

The remainder of this section looks more into the four most frequently referenced drivers: legislation; customers; employees; and partnerships.

LEGISLATION

Literature finds authorities and certification bodies important external driving forces (cf. Tables 4-3 and 4-4). This is because they impose legislation, financial incentives and disincentives, and act as whistle blowers around environmental management (Erlandsson & Tillman 2009). Bey et al. (2013), Johansson & Sundin (2014) and Reyes et al. (2006) identified legislation as the most important driver. Interestingly however, none of the authors in cited compliance with legislation as beneficial to ecodesign. Short et al. (2012) and Zutshi & Sohal (2014) mentioned risk aversion but this does not necessarily relate to legislative compliance as it could also relate to brand image or competitiveness.

For initial implementation, only companies C and F identified legislation as a core driver. Initially, company C began investigating chemical, waste and energy legislation. This was out of concern that their national government expected them to be a front-running company. Company F also approached ecodesign proactively by assessing the toy sector’s chemical and waste legislation in anticipation of future legislation in their healthcare sector.

For current practice, legislation still drives company F and has become a motivation for companies D and E. The increase from two respondents in initial implementation to three in current practice could be associated with the increase in product related requirements and market mechanisms. Surprisingly, only two respondents (F and G) highlighted potential or upcoming legislation to be an influencing factor, but in the case of G this was not a core driver. Company C admitted that it was no longer motivated by existing or future legislation. This is because they had become compliant and their internal factors i.e. core values and strategy had become stronger motivators.

This research finds that legislation is an external driver because it is listed in both initial and current practices (referenced five times by four companies). However, in initial implementation it is not the most predominant (compared to partnerships), nor is it in current practice (compared to customers). Also, respondents spent more time discussing other drivers despite a high number of responses for legislation.

CUSTOMERS

Literature also regards customers as an important external force (cf. Tables 4-3 and 4-4). This is because customers make their purchasing decisions on the availability of environmental information and the environmental impacts of products (Ammenberg & Sundin 2005; Erlandsson & Tillman 2009; O'Hare 2010). Research by Short et al. (2012) and Bey et al. (2013) found that customer demand was the first and second most important ecodesign driver, respectively. van Hemel & Cramer (2002) also saw that customer demand was stronger than legislation. Similar to literature findings about legislation, none of the authors that referenced customers as drivers mentioned customer satisfaction as a benefit of ecodesign. However, improved relations (Plouffe et al. 2011) and enhanced brand image (Bey et al. 2013; Johansson & Sundin 2014; O'Hare 2010; Plouffe et al. 2011; Reyes et al. 2006; Zutshi & Sohal 2004) were noted benefits alluding to customer satisfaction.

For initial implementation, none of the companies identified customer demand as a core driver, which is in contrast to literature. One explanation given by company B was that awareness of ecodesign (and environmental issues more generally) in the mid-1980s and 1990s was low and not of high societal demand. Another reason could be due to the type of industries the companies operate in e.g. industrial equipment vs. consumer durables and type of customers e.g. business-to-business or business-to-customer.

For current practice, customer demands increased in importance, as the number of respondents increased from zero to four. This could be associated with an increased awareness in product related requirements and market mechanisms. Companies C, D, E and G identified customers as drivers however not as the primary driver. Company G made the differentiation that the demand was for more documentation i.e. EPDs rather than for actual product improvements e.g. improved logistics via reduced service intervals or extended lifetimes. Company E also informed that customer demand was not their primary driver because the business case for reducing fuel emissions was logical and the industry specific legislation was strong. Further, customers of company E were more interested in personal benefits i.e. increased savings from fuel economy rather than environmental benefits i.e. reduced emissions.

This research finds customer demand to be an external driver of some importance based on a high number of responses (four references). However, companies have experienced lower than expected customer requests which reduces motivations for ecodesign. Similar to legislation, respondents spent more time discussing other drivers despite a relatively high response rate.

EMPLOYEES

In literature, both upper management and employees (individuals or groups) constitute important internal drivers because they initiate environmental initiatives (O'Hare 2010). Although environmental change can emerge from anywhere in a company, management support is cited as an essential success factor (Erlandsson & Tillman 2009). In the literature review however, managers and employees were given equal importance (cf. Tables 4-3 and 4-4). Literature further emphasized management commitment i.e. in the forms of policies and resources allocated but not managers specifically as change agents. This implies that even if management commitment is present, a company still needs a dedicated group of employees to carry out ecodesign. Regarding employees, Bey et al. (2013) and Plouffe et al. (2011) also acknowledged that their satisfaction was a benefit, and therefore a driver of ecodesign.

For initial implementation, management and employees constitute important internal drivers because companies referenced them four of five times. Of the two, employees were more important than management as they were referenced three to one times, respectively. In fact, single employees were most sited initially. A regulatory expert (company E) and a senior environmental specialist (company G) initiated the ecodesign activities out of a desire to contribute positively and proactively. In company E it was about showing the importance of material choices, while in company G it was about expanding their activities from a cleaner production perspective and fulfilling a corporate requirement. The respondent for company B was one of the initiators in 1992 and spoke in plural to indicate it was a group effort at the onset from the R&D function. He supplemented by saying it was a proactive approach because they experienced low external pressures and that management (although not referred to as a core driver) had quickly bought into the concept. Company D was the only company that referred to management as an initial driver;

their management realized the benefits of optimizing their product from an energy efficiency perspective.

For current practice, management and employees remain important internal drivers because they corresponded to all six of the references. Employees remained the same based on total number of references (three) but shifted to indicate the growing importance of employee groups as opposed to single employees. Employees from R&D and environmental functions in company B continue to be proactive. Despite implementing ecodesign later than other companies, company G's single environmental specialist established a small group to address product oriented environmental topics within a short period. Company F claimed ecodesign was prompted from employees who thought they weren't doing enough, especially regarding specific material phase outs. The other companies likely have groups working on product oriented environmental topics but they did not identify them as core drivers.

Management gained importance in current practice, increasing from one to three references. Companies A, B and C informed of enhanced management support. Company A appointed a new CEO in 2008 who was interested in the subject and who later launched a company-wide sustainability program. Management in B also realized the benefits of optimizing their product from an energy efficiency perspective. Likewise, management in C realized the cost benefits of reducing materials and packaging. Company D however reported a decline in management support since the onset of ecodesign. The respondent indicated that few resources or support were allocated by management despite the presence of drivers i.e. legislation, customer demands and a sound environmental strategy.

This research finds that both managers and employees represent important internal drivers. However, employees are found to be stronger than managers (six to four references). Ecodesign is often driven by R&D or environmental specialists and communities seem to naturally evolve to include more specialists. Management support is especially weak in the initial stages of implementation, which could be due to low awareness.

PARTNERSHIPS

In literature, partnerships are especially important for systems based environmental change. This is because activities like ecodesign, sustainable supply chain management and circular economy require the inclusion of a broader set of external stakeholders (Grekova et al. 2015; Junquera et al. 2012; Stevels 2009). Partnerships for environmental change typically occur between companies, municipalities, academia, suppliers and other value chain actors, customers, NGOs, etc. The Triple-Helix concept promotes environmental progress through the combined involvement of actors from the private, public and research sectors (Karlsson et al. 2010).

Albino et al. (2012) found that inter-organizational collaborations are beneficial to a company's environmental performance. Other authors identify the following benefits related to partnerships: environmental performance improvements (Junquera et al. 2012) e.g. to products (Polonsky & Ottman 1998; Stevels 2009) or internal processes (Grekova et al. 2015; Stevels 2009; Zutshi & Sohal 2004); expanded scope of environmental issues (Polonsky & Ottman 1998); increased innovation (Grekova et al. 2015; Junquera et al. 2012); higher credibility or competitive advantage (Junquera et al. 2012; Polonsky & Ottman 1998); enhanced learning and knowledge sharing opportunities (Albino et al. 2012; Aschehoug et al. 2012; Grekova et al. 2015). However, none of the authors in cited partnerships as a means for ecodesign; they indicated specific stakeholder groups but this was regarding demands rather than collaborations. This is also supported by different authors that indicated a shortage of customer involvement (Grekova et al. 2015; Junquera et al. 2012) and supplier collaborations (Grekova et al. 2015; Zutshi & Sohal 2004) in product development processes.

For initial implementation, partnerships represent an important driver because all seven companies revealed that some form of external collaboration occurred. Industry associations, ministries, universities and NGOs were important actors in these partnerships. Three companies specifically referenced partnerships as core drivers (B, D and G), representing the strongest motivation of both internal and external drivers. Company B had initiated ecodesign in participation with a national industry association, while company D had ongoing partnerships with the national environmental ministry and a local university. University collaboration and industrial researchers were essential to company G. University students were also important for companies C and E but not a core driver. Company F initiated ecodesign through an EU driven project but did not indicate this as a core motivator. NGO's were also important stakeholders during initial implementation for companies A and C. For most of the companies, external collaborations revolved around LCAs in the mid-1990s and early-2000s at either the governmental, university or industry level.

For current practice, the same companies initially engaging with universities made some reference to continued collaborations (C, D, E, G) and company B indicated recent academic affiliations. However, partnerships were not explicitly mentioned by any of the companies as core drivers for continued ecodesign practice. We assume all companies are engaging despite no explicit reference to other external stakeholders throughout the value chain e.g. customers, suppliers and other value chain actors, industry associations, NGOs, governments, etc.

This research finds partnerships to be an external driver of somewhat importance based on a moderate number of responses (three references). It was a surprising finding that the companies did not associate partnerships as a higher driving force particularly for current practice. Based on experience and literature, we believe that external partnerships are a critical element for the success of ecodesign and other environmental change.

4.4.2. BARRIERS CHALLENGING ECODESIGN PRACTICE

In line with the drivers in section 4.4.1, this research differentiates between ecodesign barriers during initial implementation and current practice; initial barriers are defined as factors that hinder companies abilities to engage with ecodesign for the first time, while current barriers depict the current (at the time of the interviews in 2013) limiting factors that prevent companies from practising ecodesign after initial implementation. A comparison between internal and external barriers during both time periods is provided in Table 4-8.

Based on interview responses in Table 4-8, the following can be summarized:

- Ten barriers were identified by respondents.
- Respondents referenced barriers 16 times in initial implementation and 24 times in current practice.
- Uncertain business relevance or value; limited awareness of the life cycle or uncertainty of impact categories; and weak management support were cited as the three most significant barriers amongst the companies, based on response numbers. Uncertain business relevance or value was referenced six times by six companies; limited awareness was referenced seven times by five companies; and weak management support was referenced six times by five companies.
- In initial implementation, unclear business relevance or value was the largest challenge with four companies. Limited awareness of the life cycle or uncertainties in impact categories; weak management support; and the lack of a central platform or process integration were equally the second predominant challenges, with three companies citing each.
- In current practice, limited awareness of the life cycle or uncertainties in impact categories continued to be the biggest challenge for four companies (an increase in references by one company). Lack of employee ownership; lack of a central platform or process integration; and priority against other design parameters were equally referenced as relatively high challenges, with three companies citing each.
- Response variety was lower for barriers in initial implementation compared to current practice.

The remainder of this section looks more into four specific barriers: leadership commitment (in terms of both management support and employee ownership); ambiguous business relevance or value and communication.

TABLE 4-8.COMPARISON BETWEEN BARRIERS DURING INITIAL AND CURRENT (2013) ECODESIGN PRACTICE

Barriers	Initial implementation	Current practice
Uncertainty of business relevance or value	B, C, D, G	E, F
Limited awareness of life cycle or uncertainty of impact categories	A, C, E	A, C, D, G
Weak management support	A, C, G	D, F, G
Lack of employee ownership		D, F, G
Lack of central platform or process integration	C, D, G	C, D, G
Communication challenges	B, E	F, G
Priority against other design parameters		B, C, F
Approach from a natural rather than social science perspective		B, C
Lack of customer demand	A	A
Ability to fulfil stricter legislation		E

LEADERSHIP

Leadership is an important element in section 5 of the ISO 14001 standard (ISO 2015) for ensuring commitment. Ammenberg & Sundin (2005) indicated commitment at both strategic and operational levels of a company as important. In this paper, leadership represents a combination of management support at the strategic level and employee ownership at the operational level. Management support is characterized by the active promotion of e.g. strategies, policies and programs, and the allocation of resources e.g. financial and human capital. Employee ownership is characterized by the degree of responsibility an employee holds and the extent to which they exert that responsibility by taking action. Employee ownership can also be defined by the degree of ecodesign implementation in processes and routine practices by all organizational functions.

Management support

Literature finds management commitment to be an essential success factor for the implementation of cleaner production initiatives (Stone 2006a). ISO 14006 (ISO 2011) outlines the role of top management and indicates its importance for sufficiently embedding ecodesign within an organization. The international standard stresses that ecodesign issues need to be built into management thinking, reporting and practice. Ammenberg & Sundin (2005) informed that management support can be demonstrated through resource allocation and formal written procedures, while Stevels (2009) stressed the need for clear strategies and information systems. Further, O'Hare's study (2010) found that explicit management support is a prerequisite for employee ownership. Despite this, a number of authors reference management barriers (cf. Tables 4-5 and 4-6). Some of those authors cited managerial support as one of the key barriers to the integration of ecodesign (Bey et al. 2013; Murillo-Luna et al. 2011; Reyes et al. 2006). Other commonly cited barriers related to management included: lack of strategy (Ammenberg & Sundin 2005; Bey et al. 2013; Erlandsson & Tillman 2009; Reyes et al. 2006) and resource allocation (Ammenberg & Sundin 2005; Bey et al. 2013; O'Hare 2010; Reyes et al. 2006; Short et al. 2012). Stone (2006a) also found that in cleaner production initiatives there were challenges not just in gaining management support but also in maintaining management support for continuous improvement.

For initial implementation, companies A, C and G explicitly identified low management support as an initial barrier. They also related weak management support specifically to a weak strategy and lack of resources. Conversely, three companies experienced moderate to high management support initially (B, D and F). Company B indicated that ecodesign was always promoted by management because they realized the potentials for optimizations and efficiency gains. Company D expressed that management provided a strategy and resources for improving the energy efficiency of its products and thereby its competitive advantage. Company F informed that management support was received in the form of resources for an LCA project driven by the EU. However, only company D identifies management as an initial core driver in Table 4-7.

For current practice, management support remained a core barrier for company G and became a dominant challenge for companies D and F (negative shift). Company G informed it had initiated ecodesign from the bottom-up and was gaining buy-in from some management in the form of resource allocation but informed lack of strategy was a challenge (environmental and product related strategy). Company D's management support dissipated over time despite being a core driver initially. Despite a company-wide product sustainability strategy, past achievements in product optimization (energy efficiency), high engagement in legislative activities and increasing customer demands, there were no supporting action plans or resources allocated to the topic by the management in D. Company F also affirmed a lack of ambition and strategy from management in addition to a lack of visible KPIs. Further, all of these companies informed of the tendency to focus on a single life cycle aspect i.e. energy efficiency (A), material substitution (F) or only production-oriented activities (G). Although management was not cited as a core barrier for company E, the respondent admitted that management support came in waves and the company had worked mostly with production-oriented activities. This correlates to another barrier cited by companies: limited awareness of the life cycle or uncertainty of impact categories.

Conversely, management support became a core driver for A, B, C (as seen in Table 7) and no longer represented a barrier for A and C (positive shift). In company A, senior management began to drive product-oriented activities and allocate resources. This was mainly due to a new CEO (2008) who prioritized sustainability issues and introduced a new company-wide program. Company B informed management developed long term objectives. Despite strong leadership, the respondent still expressed the need for stronger management leadership in order to achieve radical changes where engineers had little authority. The respondent also suggested to link environmental activities to cost and profit centres (via environmental accounting) in order to engage management even more.

This research is in line with literature findings, where a number of companies indicated challenges related to management support during both initial and current practice. A lack of strategy and a lack of resources were a reflection of weak management support. This research also finds that management tends to become complacent with current forms of environmental management; managers do not understand the principles of life cycle thinking and continuous improvement, which are equally essential for environmental change.

Employee ownership

Yukl (2008) found that leadership can extend beyond top-level management and be exercised by other stakeholders who exert some degree of influence e.g. employees. Stone (2006a) refers to these stakeholders as “change agents”. Other authors cited employees as an essential component in the planning and implementation of environmental processes (Ammenberg & Sundin 2005; Stone 2006a, 2006b; Thabrew et al. 2009; Zutshi & Sohal 2004). Environmental activities typically require a cross functional approach so a high degree of cooperation, employee ownership and leadership are important. Hanna et al.'s (2000) study affirmed that employee involvement corresponds to improved environmental performance.

Lack of employee involvement, ownership and leadership (Murillo-Luna et al. 2011; Reyes et al. 2006; van Hemel & Cramer 2002) and limited employee motivation (Bey et al. 2013) are found to be significant barriers to ecodesign. Other employee related challenges affecting ownership include stakeholder conflicts (Reyes et al. 2006), lack of cooperation or collaboration (Bey et al. 2013; Erlandsson & Tillman 2009; O'Hare 2010; Short et al. 2012) or lack of experience or expertise (Ammenberg & Sundin 2005; Johansson & Sundin 2014; O'Hare 2010; Short et al. 2012). Lack of assigned responsibility, organizational design, lack of integrated processes, aversion to innovation and change are additional obstacles cited by authors that have effects on employee ownership (cf. Tables 4-5 and 4-6).

A number of authors cited ways in which to overcome these employee related barriers: Zutshi & Sohal (2004) and Stone (2006a) found that training is essential for gaining employee awareness and thereby involvement; employees must be adequately equipped in the form of knowledge, skills, experience and motivation. Ammenberg & Sundin (2005) found that environmental initiatives are generally designed and maintained by environmental functions and can be a reason for low ownership from the broader group of employees. Zutshi & Sohal (2004) and Thabrew et al. (2009) also found that employees are generally involved in later stages of environmental activities e.g. operational implementation rather than strategic planning of policies, procedural designs or tools; employees must be invited to contribute as early as possible so they can influence and share control over the initiatives, decisions and resources affecting them (ISO 2011). Transparent access to information, communication and consensus building (Thabrew et al. 2009) and cultivating a commitment to belonging to a socially responsible culture (Stone 2006b) are also deemed important criteria for employee ownership.

For initial implementation, none of the companies referenced employee ownership as a core barrier. This is likely because there were a high number of employees who took responsibility in the initial stages as explained in 4.4.1. However, the majority of these employees represented environmental functions and the degree of ownership in other functions is assumed to be low, with the exception of companies B and E (that had motivated engineers). However, companies D and G indicated that engineers and project managers were consulted in the early stages. This is also supported by the fact that the implementation across business was relatively low in the initial stage; all of the companies indicated ad hoc approaches that were narrow in scope. Company C admitted having difficulties applying a company-wide approach from the beginning, and emphasized the need to start in one business unit or function. The respondent also informed that ecodesign was too often seen from a technical perspective:

> *"We once thought ecodesign was successfully implemented when we had compiled our bag of tricks and tools. However, we learnt through time that ecodesign was broader and more dependent on the human aspects e.g. employee ownership"*.

For current practice, three companies cited employee ownership as a barrier (D, F and G). Company D indicated that some engineers had initially adopted energy efficiency into their design practices but environmental functions remained the drivers. The respondent also indicated the lack of a burning platform for carrying out product-oriented environmental activities. Company F also informed of similar problems. Company G specifically referenced its engineering functions as lacking ownership but commended its project management, communications and sales functions. On the other hand, companies A, B and E indicated a high awareness and level of ownership in environmental issues across their businesses and admitted to seldom receiving resistance from other functions. Company B expressed the importance of having more employees do a little, then less to do a lot; but also explained that more sustainability leadership and engagement is needed from employees, management and society, alike. Interestingly, the respondent also expressed the need for environmental functions to take more ownership in learning the core business and understanding how to better translate ecodesign activities into business value for engineers and managers.

Regarding organizational structure, companies C, D, F and G currently operate as centralized environmental functions. Company B also operates centrally but from its R&D function. Conversely, companies A and E have a decentralized structure where stakeholders from other functions are responsible and a small corporate environmental function for support. Further, companies A, B, F and G referenced the use of systematic procedures and processes e.g. stage gate model, guidelines, etc.

This research finds that ownership from cross functional employees is essential for ecodesign success. Employee ownership was higher initially, which was likely related to (mostly) environmental functions driving the ecodesign agenda. However, ownership gradually became a barrier for three of those companies who could not secure buy-in from other functions; this might be associated with the weak management support these same companies experienced in current practice. Companies employing ecodesign through a decentralized approach experienced less resistance than those using a centralized approach. This is also true for company B who managed ecodesign from its R&D function. One of the companies also stressed the importance of environmental functions increasing their understanding of other functional areas in the company; this would ensure better alignment of environmental activities with other functional processes.

BUSINESS RELEVANCE AND VALUE

Literature finds that there are a number of benefits transitioning from firm based to systems based environmental activities. Some of those cited include: competitive advantages; enhanced brand image; advances in innovation; compliance; cost reductions; improved relations; and product or process improvements. Albino et al. (2009) emphasized that environmental related activities should not be seen as additional costs. Conversely, such activities generate improved efficiencies; return on investments; increased sales; new product markets; improved corporate images and brand value; product differentiation; and enhanced competitive advantages.

However, ambiguity often exists around the relevance and value of ecodesign for both managers and cross functions outside the environmental field. Business cases have increasingly been used to justify environmental activities in response to this (Carroll & Shabana 2010; Salzmann et al. 2005; Schmidt 2003; Veshagh et al. 2012).

For initial implementation, identifying the business relevance/value was a challenge for four companies (B, C, D and G). Company B suggested that the maturity of ecodesign as a subject might be associated to its perceived relevance and value; the respondent justified this by comparing when the environmental and the economics fields emerged (1980s and 1780s, respectively). The respondent also explained that even though managers and employees were relatively supportive in the beginning, their fundamental understanding of the benefits and value affected their perceived relevance of ecodesign. This could have also been associated with a lack of external drivers i.e. legislation and customer demands, which otherwise makes ecodesign relevant. Companies C and D initially focused on a single environmental issue i.e. substance management and energy efficiency respectively, which could have limited their ability associating the relevance of other ecodesign parameters to their products or operations e.g. environmental topics, life cycle stages, impact categories, etc. While for company G, relevancy challenges were related to engineering functions not seeing the applicability of ecodesign to their work. Further, the need to justify the relevance/value of ecodesign could also be associated with weak management support in companies C and G.

For current practice, identifying the business relevance/value was no longer a challenge for the companies that initially referenced it, but became a challenge for two different companies (E and F). Company E informed that it was due to a lack of customer demand; fuel efficiency was important to customers but they were not willing to pay more for additional efficiency or improvements related to other environmental topics e.g. material recyclability, etc. The company could not justify additional ecodesign in their operations and the ecodesign activities that were occurring in-house were eventually outsourced i.e. LCA. Company F was fairly proactive in the beginning, focussing on material phase outs in the fear of future legislation. The respondent informed that over time, management challenged the relevancy of additional ecodesign activities and associated these difficulties to current market conditions that were affecting prices. It was indicated that their original, broad and long term vision was narrowed; their proactive activities were reduced to remaining abreast of legislation and customer requests. However, the respondent saw the challenge positively as he believed it helped them to better understand their end users and the public's expectations and requirements. He also stressed the importance of sharing positive wins to both management and other cross functions. Further, the need to justify the relevance/value of ecodesign could be associated with weak management support and a lack of employee ownership in company F.

For overcoming this challenge, the presence of a motivated employee was helpful in companies B and G and management in company C. Companies C, F and G also expressed the importance of gaining credibility through small successes and showcasing how ecodesign was aligned and valuable to their companies' image, product portfolio and operations. However, company C warned the time required for building credibility with management; it wasn't until management learnt of the respondents engineering background and employment history that they considered him "one of them" and thereby acknowledged his tasks as relevant/valuable. While company B stressed the need for more environmental champions to have business and financial competences in order to understand how things work, how to translate meanings, where environment could positively contribute.

This research finds that despite the many benefits associated with ecodesign, the relevance/value of ecodesign was unclear for six of the seven companies. Four of these companies were able to overcome this barrier by demonstrating the operational relevance and business value to managers and other cross functions. However, for two additional companies it became a current challenge. In line with literature, some of the companies faced ambiguity about the relevance/value but were able to overcome this through the use of business cases and by aligning with other operations. Further, a motivated employee that had high credibility and a strong business understanding proved useful.

COMMUNICATION

Communication represents the way in which ecodesign and other product oriented environmental activities are communicated internally and externally. Communication is an important element in section 7 of ISO 14001:2015 and section 5.4.3 of ISO 14006:2011. Both standards require companies establish, implement and maintain communication procedures that foster two-way communication, both in the internal and external value chains. Internally, communication should focus on the products' environmental performance and be communicated at various levels and functions throughout the organization. External communication should support collaboration among various parties throughout the value chain, relating to both the analysis of, and possible solutions to, the environmental impacts throughout the entire life cycle of a product (ISO 2011). There are several other ISO standards that support companies in their communication of environmental activities i.e. ISO 14063 and ISO 14020 series.

Godemann & Michelsen (2011) labelled communication as a persuasive instrument that does much more than just inform or transfer knowledge:

> *"This potential to shape or optimize is a constitutive element of environmental communication, which is understood as a controllable process or single action"* (p.28).

Stone (2006b) also stressed the criticality of communication for effective cleaner production activities but highlighted the underutilization of communication strategies. She informed that companies often perceive environmental policies as being sufficient communication forms. Post & Altma (1994) found that the quality of communication is a significant barrier for environmental management and described the quality of communication as the distance between management commitment and the actions occurring throughout the organization. To improve communication, they suggested that it be treated as a critical business process and communication champions be deployed throughout all levels of the organization. While Stone (2006b) suggested three effective communication forms: (1) top-down e.g. communication of commitment, (2) bottom-up e.g. communication of program needs and results, and (3) lateral e.g. communication to involve other staff or stakeholders.

Other literature found the following barriers related to communication: a lack of policies or strategies (Ammenberg & Sundin 2005; Erlandsson & Tillman 2009; Murillo-Luna et al. 2011; Reyes et al. 2006); insufficient information and knowledge (Ammenberg & Sundin 2005; Johansson & Sundin 2014; O'Hare 2010; Reyes et al. 2006; Short et al. 2012) – with Bey et al. (2013) ranking it as the largest barrier to ecodesign; poor understanding of customer needs (Short et al. 2012); and complexities related to the use of tools (Bey et al. 2013; Johansson & Sundin 2014; Reyes et al. 2006).

For initial implementation, companies B and E cited challenges related to internal and external communication, respectively. For B their ecodesign tools were overcomplicated which hindered their use internally, while for E there were uncertainties in the scope that should be used for assessing environmental impacts and transparently communicating them externally.

For current practice, companies F and G indicated a new challenge related to communication. For F it was also about transparency and the degree of openness in communicating not just successes but also challenges with business partners. For G there were uncertainties in what environmental topics were important to their customers. The respondent also informed the company had a clear product strategy but it lacked explicit reference to the environmental benefits. Furthermore, all respondents indicated the importance of internal and external communication alike, and all agreed it did not receive adequate attention in their respective companies.

For overcoming communication challenges, company B decreased the complexity of their tools; they began using a simplified checklist with eight bullet points and provided training material on the intranet. In line with Post and Altma (1994) the respondent informed of the responsiveness managers and environmental functions need to possess:

> *"Environmental functions are often speaking to the deaf ears of other cross functions, and vice versa. We commonly overlook that people are sitting in very different worlds and we are communicating a new element that is strange to them. […] To overcome this, we must translate meanings and create mutual understandings. […] This is where the use of engagement platforms and nudging can help to change environmental awareness and behaviours".*

Company B also expressed a desire to improve the environmental awareness beyond management and cross functions but to external stakeholders.

All of the case companies currently utilize both internal and external communication channels to inform of environmental activities but to a lesser degree ecodesign activities. None of the companies explicitly cited the use of a communication strategy for product related environmental activities. After cross-referencing this to content available on each of the companies' websites: six companies referenced ecodesign or product sustainability (A, B, C, D, F, G); four companies referenced the use of LCAs (A, B, E, G); one company (B) made EPDs easily available on their website (B); one company provided long term policies and ambitions for product environmental protection (B); and all of the companies published sustainability reports. However, many of the sustainability reports did not specifically address product related information.

This research finds that communication represents a larger barrier than the companies indicated; despite four companies citing it overall. We assert that communication is the basis for many of the other barriers e.g. ambiguities around business relevance or value, management support and employee ownership, limited awareness of life cycle or uncertainties in impact categories, etc.

4.5. ORGANIZATIONAL DEVELOPMENT FRAMEWORK

Around 70 per cent of all change initiatives fail (Balogun & Hailey 2004). Boonstra (2004) suggests this is because the two dominate strategies used to manage change are based on considerably different assumptions about the character of change, the individuals involved and their degree of learning. These strategies are: (1) planned change, and (2) organizational development; the first of which is more commonly applied by companies.

Planned change is characterized by conscious and deliberate changes that are typically managed from the top in order to create economic value. This strategy is also referred to as the stage theory because change is achieved by modifying formal procedures in a company and following a series of rational steps. Here, change is seen as a linear approach and treated as a single occurrence that can be controlled. However, the planned approach often fails to recognize the human factor (Graetz & Smith 2010). The stage-gate model for product innovation is an example of planned change, where multiple development phases lead to an outcome – a new or revised product.

In contrast, organizational development focuses on the humanistic aspects e.g. organizational learning, knowledge management and transformation of norms and values in order to develop individual competencies rather than formal procedures and processes. In this strategy, change cannot be planned because it is viewed to be emergent and based on an iterative process of stakeholder interactions and learning. Learning and participation are central means of organizational development and are mutually dependant for creating change or enhancing performance. The social practices are thus emphasized instead of the formal procedures in a company.

Within organizational development theory, knowledge management (KM) has emerged as a distinct field in which organizational learning and performance improvement are the primary outcomes. As seen in Figure 4-1, KM processes directly improve organizational processes e.g. innovation, individual and collective learning and decision making. Further, improved organizational processes produce intermediate outcomes e.g. better decisions, products, services and relationships, which ultimately improve organizational performance (King 2009).

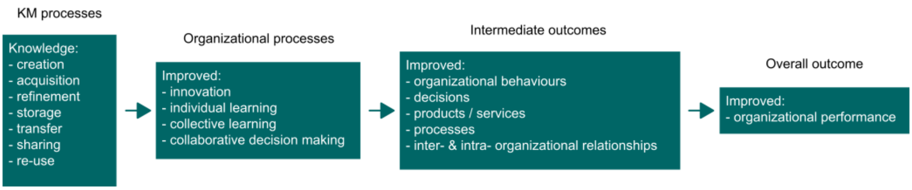

FIGURE 4-1. KNOWLEDGE MANAGEMENT AND ITS EFFECTS ON ORGANIZATIONAL PERFORMANCE (KING 2009)

Argyris & Schön's (1978) double-loop learning is a classic concept from KM theory. Other authors refer to it as third-generation organizational development (Benn & Baker 2009) or third-order learning (Tosey et al. 2011). Lave & Wenger's (1990) notion of situated learning in Communities of Practice (CoP) extends individual learning to group learning. CoPs are a way to stimulate learning in organizations by enhancing knowledge exchange and collaboration (Mittendorff et al. 2006). CoP can be considered a social system, in which learning occurs as a result of the participation and engagement of community members. It is through the interplay of participation and reification (as seen in Figure 4-2 through the use of formal procedures e.g. tools, processes, etc.) that sense making occurs and knowledge is generated. In that sense, iterative and interactive processes foster learning because individuals exchange meanings, experiences and knowledge (Boonstra 2004).

Change is an outcome of the relational, learning process between individuals in a community. As a community's members develop competencies, change occurs at individual, community and company levels.

Authors relating successful organizational change to stakeholder interactions include Guzzo et al. (1985), Pasmore & Fagans (1992) and Schein (2004). Other authors explicitly advocate change through the use of CoP including Birdwell-Mitchell (2016), Brown & Duguid (1991), Cordery et al. (2015) and Hendry (1996). Relating specifically to ecodesign studies, Verhulst et al. (2007a) inform of how the human dimension is exempt in many ecodesign studies and more specifically participation and empowerment. They propose cross-linking other disciplines to the study of ecodesign e.g. industrial and organizational psychology as well as change management. For representative ecodesign literature focusing on the "soft" side and human mechanisms of ecodesign implementation are described and based on a number of organizational theories refer to Table 4-4. The literature is presented in chronological order to show the evolution in this specific field of ecodesign research. Change management is the predominant organizational theory used by the literature (Brones et al. 2016; Lozano 2012; Stone 2006a, 2006b; Verhulst et al. 2007a, 2007b) with fewer works addressing ecodesign through the lens of organizational development and KM (Benn & Baker, 2009; Cohen-Rosenthal 2000) and only one using a CoP approach (Skelton et al. 2016).

In the context of CoP, Wenger (1998) uses the notion of duality to depict the tensions between two opposing forces, participation and reification. He describes the duality as:

> *"A single conceptual unit that is formed by two inseparable and mutually constitutive elements whose inherent tensions and complementarity give the concept richness and dynamism"* (p. 66).

In the context of ecodesign this can be related to the reported challenges between the interplay of technical and human mechanisms (Figure 4-2). Both are important to ecodesign practice and are in a sense, mutually dependent because they dually exist, interact and thereby affect each other.

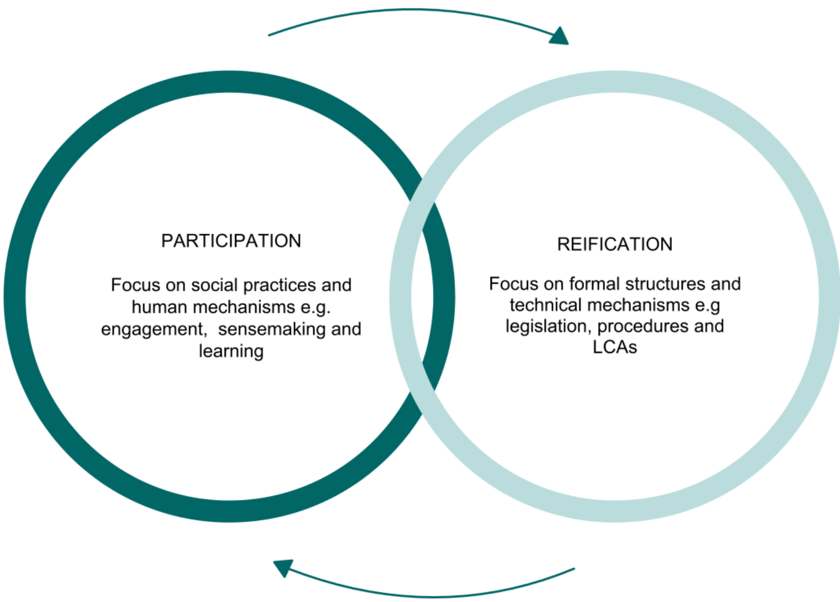

FIGURE 4-2. THE DUALITY OF COP AND THE INTERPLAY BETWEEN TECHNICAL AND HUMAN MECHANISMS RELATED TO ECODESIGN

A significant amount of companies and ecodesign literature focus on the right circle in Figure 4-2, putting emphasis on legislation, impact assessment tools and company structures. There are fewer reports on the use of tools and processes as boundary objects for *engaging* with stakeholders, *motivating* interest, *developing* cultures of awareness and *encouraging* participation in ecodesign. Further, the dynamics between members of different communities such as environmental and engineering departments are often underplayed. Ecodesign practice can be enhanced by focusing on the interactions and learning between communities and individuals (left circle in Figure 4-2). This can be done by employing a social learning approach to organizational change and development.

We suggest that strategies that encompass learning susch as organziational development are likely to be more effective in obtaining higher levels of environmental change. Figure 4-3 is based on former works including Lozano's (2012) sustainability change model and Adams et al. (2012) three stage sustainable innovation framework. It shows how ecodesign (or other environmental activities) can emerge using an organizational development strategy which is based on learning within communities. The model depicts an iterative process of change at various levels e.g. firm (micro), value chain (meso) and system (macro) and it acknolwedges that drivers and barriers have the ability to change over time according to the different levels.

Wenger et al. (2002) indicate that communities can either emerge on their own or be encouraged and cultivated. The grey stars represent CoP where individuals from different communities interact. Through this interaction process, individuals question the validity of their current and future practices; where practices can denote meanings, social norms, decision making structures, activities, relations and processes. The interplay of participation and reification (Figure 4-2) stimulates a process of sense making, reflecting and learning at the individual and community levels. Community interactions thereby help to deconstruct existing knowledge and status quo environmental practices in order to generate new knowledge and more environmentally oriented behaviours. The use of CoP can thus support a shift from traditional, firm based activities at the micro level e.g. product and technology improvements to broader, value chain and systems based activities at the meso and macro levels e.g. ecodesign, circular economy, etc.

4.6. CONCLUSIONS

Initially, the drivers and barriers to ecodesign were analysed and how these might change over time. In response to the first goal, a summary of these are provided in Tables 4-9 and 4-10.

The number of drivers motivating ecodesign practice increased over time, while the variety of drivers decreased. The companies indicated a higher number of external drivers in initial implementation but they became more internally driven over time. The types of drivers changed over time for most companies. When summed, legislation; customers; and management were cited as the most significant drivers. However, discussions indicated that employees and partnerships were in fact as important.

TABLE 4-9. FINDINGS REGARDING DRIVERS TO ECODESIGN PRACTICE

Drivers	Findings
Legislation	Important but not a predominant driver in contrast to literature. Respondents highlighted other drivers i.e. partnerships and employees.
Customers	Important but does not influence ecodesign due to low or absent demands in contrast to literature.
Employees	Management cited more frequently then employees but respondents highlighted employees equally valuable for driving ecodesign if management support was missing.
Partnerships	Important driver in initial implementation but a lack of references in current practice.

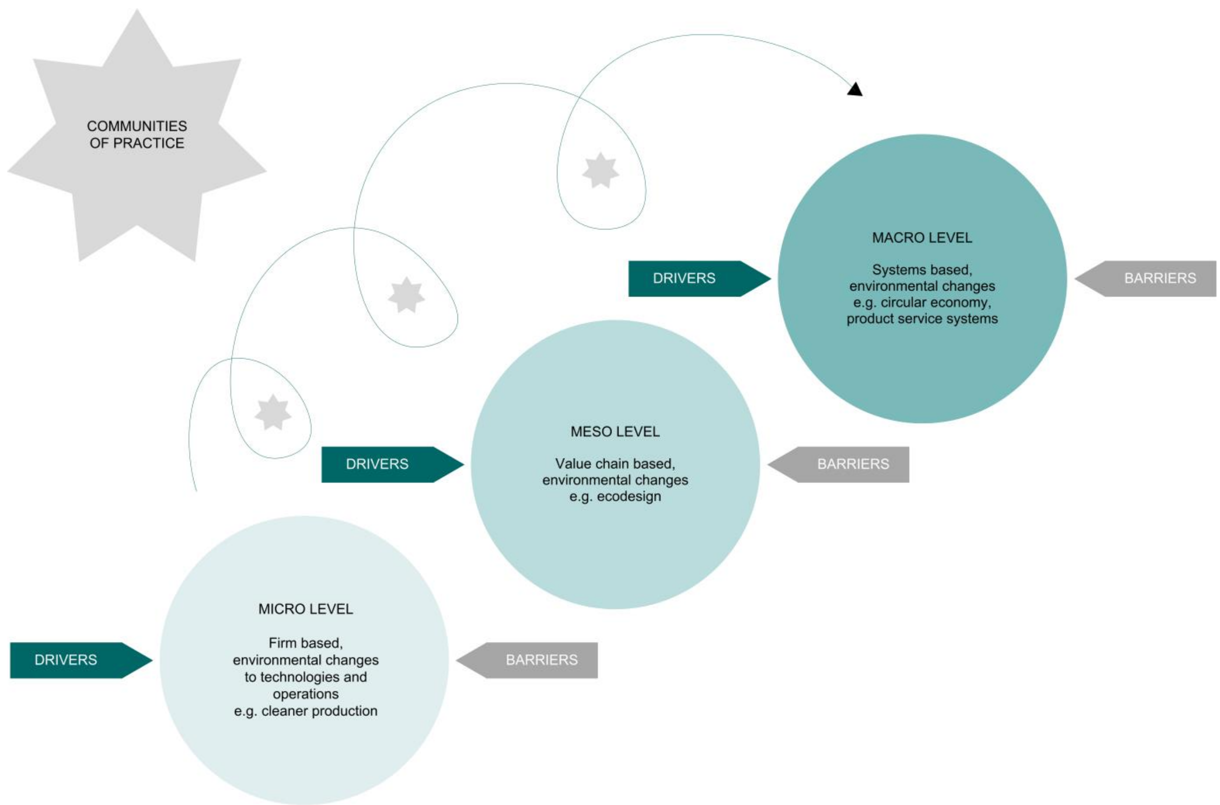

FIGURE 4-3. ORGANIZATIONAL DEVELOPMENT FRAMEWORK SUPPORTING ECODESIGN IMPLEMENTATION BASED ON COP (ADAPTED FROM LOZANO 2012; BRONES ET AL. 2016)

Both the numbers and variety of ecodesign barriers increased over time. The types of barriers changed over time for most companies. When summed, uncertain business relevance/value; limited awareness of the life cycle or uncertainty of impact categories; and weak management support were cited by the companies as the three most significant barriers. Upon further analysis however, the interviews revealed that communication was a larger challenge than indicated and is the basis for a number of other barriers.

TABLE 4-10. FINDINGS REGARDING BARRIERS TO ECODESIGN PRACTICE

Barriers	Findings
Leadership	Management and employees tend to become complacent due to a lack of understanding of the principles of life cycle thinking and continuous improvement. Both management support and employee ownership and engagement essential for successful ecodesign.
Relevance/value	Despite associated benefits, ecodesign remains unclear for managers and employees. If the business relevance and value gains can be clearly communicated then leadership from management and employees can be gained.
Communication	Represents a larger barrier than the companies indicated and is the basis for a number of other barriers e.g. management support, employee ownership and business relevance/value.

We also considered what measures are used to overcome ecodesign challenges. In response to the second goal, a summary of these are listed in Table 4-11.

Generally, there is a strong indication that the barriers were similar despite differences in the companies' contexts, industries and drivers. Changes in drivers and barriers are likely due to changing contexts within the companies and the markets in which they operate. Nonetheless, companies require increasing levels of flexibility and adaptability to adequately respond to shifting drivers and barriers.

Addressing the third goal, planned approaches to change cannot effectively manage the complexities that come with a broader value chain or systems based activities and a wider range of stakeholder perspectives. Significant organizational change is required for companies to extend beyond their traditional, firm based environmental activities such as cleaner production, to more value chain and systems based sustainability activities e.g. ecodesign and circular economy.

In response to the growing interest in the "soft" side of ecodesign or the human and social practices necessary for successful change, we presented an organizational development framework for ecodesign in the second part of this research. The framework emphasizes reflective and social learning by advocating Wenger's (1998)

CoP. Participation in CoP can foster sense making and knowledge generation which are essential elements for advancing change and environmental improvements. Successful ecodesign is thus a result of reflective learning in communities. CoP can generate changes at the firm (micro), value chain (meso) and systems (macro) levels. Thus, the framework proposed can be used as a tool to foster more sustainable consumption and production in line with the twelfth the twelfth UN Sustainable Development Goal for responsible consumption and production.

TABLE 4-5. EXAMPLES OF COMPANY VERIFIED SOLUTIONS FOR OVERCOMING CITED BARRIERS

Barriers	Countermeasures
Leadership	Establishing a product strategy and measurable KPIs.
	Creating an internal champion or group.
	Determining business cases to showcase financial gains or other business benefits to gain credibility
Relevance/value	Extending collaboration with different departments throughout initial stages.
	Co-developing tools with target groups and experts.
	Collaborating externally with wider variety of partners e.g. supply chain partners.
	Creating ownership and ensuring responsibility throughout the organization.
Communication	Establishing a product specific communication strategy (internal and external material).
	Tailoring communication for different stakeholder groups i.e. reducing content complexity.
	Transparently communicating externally about achievements and barriers.
	Regularly communicating internally about strategy and providing feedback on environmental wins.

4.6.1. FUTURE RESEARCH

There are several research implications and possible ways for extending this research:

- Investigations into change and the “soft” side of ecodesign should continue from an empirical perspective.
- Attention should be given to the organizational contexts and dynamic social practices.

- An exploration of the dynamics within communities and the dualities at interplay is also suggested. For example, researching how communities can be cultivated.
- An analysis into drivers such as employees and partnerships for ecodesign could prove valuable.
- Likewise, an analysis into barriers such as leadership, business value and communication mechanisms.
- Qualitative methods with an evolutionary perspective will lend to a deeper, contextual analysis.
- Generalizability is an element so single case studies should be aligned with literature reviews or syntheses.

Organizational implications of this study suggest that CoP are an effective way to enhance learning amongst employees in order to make a transition to systems based sustainability activities and should be more actively encouraged within companies. If companies support social structures for both formal and informal interactions between stakeholders then environmental change is more likely to naturally evolve and succeed.

CONCLUSIONS: PART 1

The first part of this research had a conceptual aim to analyse the state of the art in ecodesign and communities of practice. In this chapter, a summary of the key findings as they relate to the sub-questions below and their business relevance are summarized.

What are the state-of-the-art ecodesign practices?

How can the conceptual principles of communities of practice support ecodesign?

Key findings as they relate to the first sub-question:

- Most literature concerns ecodesign during initial implementation, less is available about ongoing experiences and how to sustain momentum.
- Drivers and barriers to ecodesign are not stable and change over time but this is underemphasized in literature with the exception of Bey et al. (2013).
- The interviewed companies were more externally driven during initial implementation but with time and practice, they shifted towards being internally driven.
- Despite literature citing legislation and customers as important drivers, respondents emphasized the importance of employees and external partnerships.
- Ownership from management, uncertainties in business relevance or value and communication were the three most cited challenges.

Key findings on the value of social elements:

- Predominant focus has been given to technical tools and formal procedures rather than the social practices and “soft” side of ecodesign.
- Participation and learning are two important human dynamics.
- Employees have an essential role as brokers for coordinating and facilitating between communities of practice.
- Boundary objects are effective means for establishing dialogue, encouraging participation and improving situated learning.
- Ecodesign can be strengthened by applying principles for cultivating communities of practice which balances participation and reification.

Business relevance:

- External partnerships and motivated employees are two drivers that should be nurtured to strengthen ecodesign.

- The brokerage role has an essential role in the cultivation of communities and employees should be provided the necessary competences and support.
- Boundary objects such KPIs and business cases should be used to secure management buy-in and link environment to product strategies.
- Ecodesign should be co-developed with internal cross functional stakeholders and if possible, external stakeholders to ensure business relevance or value.
- The environmental improvements or impacts of new product developments should be regularly disseminated internally and externally to improve dialogue.

PART 2

CONTEXTUAL FRAME

5 GROWING WITH THE WIND: A COMPANY NARRATIVE

In this Chapter, I provide a backdrop for the empirical analysis about the company and the industry in which it operates. It is a descriptive chapter based on literature, company documents and my practice based experiences. Some of the details provided might seem trivial to the reader but Bryman (2012) underlines their importance because it underpins the company's practices by providing an account of the context within which those practices occur. Thus, it is in this provision that a description of the social settings, processes, communities and their practices are described below.

In section 5.1 I provide an overview of the wind power industry. It emphasizes the industry's historical evolution from a grassroots movement to a modern sector of industrial scale. The global status of installed capacity, technological descriptions of components, materials and recent innovations, value chain characteristics and shifts amongst key players are provided and highlight the industry's growth and associated challenges. The section concludes by presenting the environmental and social aspects of wind power that are commonly referenced in the scientific literature and that was confirmed by our LCA studies.

In section 5.2 an overview of the company and its contextual aspects at the onset of this study are outlined. Note that the focus will be on the legacy Siemens Wind Power, as this is when the PhD was most engaged. I describe SWP's historical development, organizational structure and practices related to the environment and product development. I also briefly describe the parent company, Siemens and outline how some of their artefacts have influenced the artefacts and practices in SWP. Discussion is organized around mostly the formal procedures but also to some degree on the social practices.

5.1. A WINDUSTRY TALE

Wind power is indirectly dependent on the suns energy. Winds occur as a result of the uneven heating of the atmosphere, variabilities of the earth's surface and its rotation. The kinetic energy in moving air (the wind) is converted into mechanical power, which can be used for specific tasks such as grinding grain, pumping water or generating electricity. Wind turbines are thus energy converters, and are today used mostly for the generation of electrical energy.

Wind is one of the oldest sources of energy and has been used for thousands of years in a wide range of applications (for historical overviews refer to (Ackermann & Söder 2002; Gipe 1995; Kaldellis & Zafirakis 2011; Mægaard et al. 2013; Musgrove 2010; Pasqualetti et al. 2004). The earliest-known vertical axis designs originated in

Persia around 200 B.C. Later these ideas was brought to Europe and changed to a horizontal axis design and was mostly used for mechanical applications. Electrification made wind power considered a technology of the past and nearly forgotten. However, the oil crisis in the 1970s and the anti-nuclear movement in the 1980s caused the resurgence of wind technologies for electrification. Between 1973 and 1986 wind turbines changed from domestic and agricultural purposes (1 to 25 kW) to utility scaled machines (50 to 600 kW) (Kaldellis & Zafirakis 2011). During the 1990s the turbines grew in size from kW to MW and in 1991 the first offshore wind farm was installed. Today, wind power is one of the fastest growing energy sources globally (Mægaard et al. 2013; Wagner & Mathur 2012) with turbines in the 7-9MW class. Both SWP and Senvion have revealed 10MW+ turbines with many other manufacturers following.

The wind energy hosts a series of advantages, which contributes to the industry's growth rate. It is a renewable energy technology that does not rely on resources to fuel, it does not produce emissions during its operation stage or hazardous waste at its end of life. Further, it is a domestic source of energy for many regions and wind farms can be built with different capacities and installed in many location types. As other energy technologies, wind power is also facing some challenges. One of the key challenges that have gained a lot of attention in recent years is the levelized cost of energy (LCoE), which has been high compared to other conventional energy sources. The wind industry has been working towards a levelized cost of energy that is competitive with the ones of conventional energy sources (European Commission 2011b; Wiser et al. 2011).

5.1.1. GLOBAL INSTALLED CAPACITIES

The global wind power capacity has dramatically increased in the last decade, nearly eight-fold. This increase is shown in Figure 5-1 as the annual installed wind capacity. The wind power industry experienced a record year in 2016 where annual installations surpassed 63 GW for the first time (GWEC 2016a) and increasing the investments in wind energy also. The electricity from wind turbines made up around 4% of the electricity demand worldwide in 2014 (GWEC 2016a; IEA 2016). Onshore wind turbines have been the most widely technology utilised but with large increases in offshore wind in recent years (GWEC 2016a).

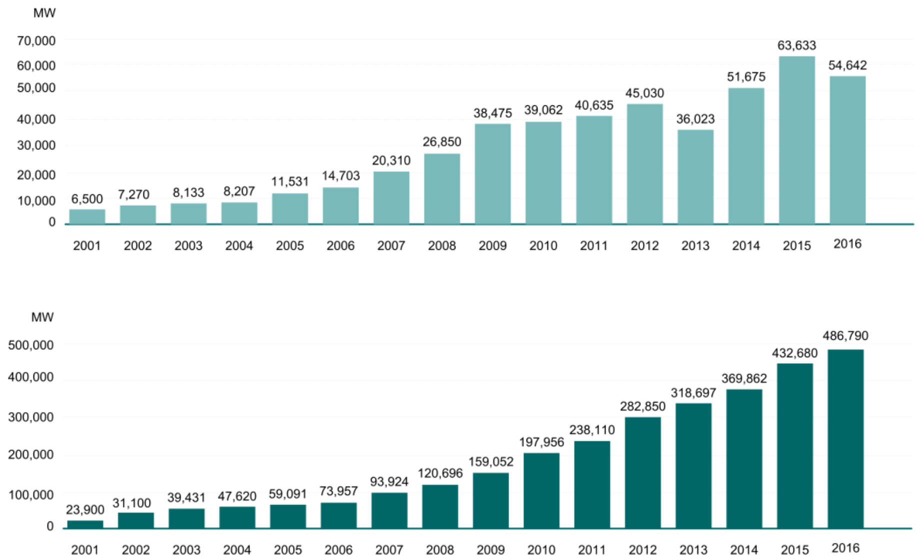

FIGURE 5-1. GLOBAL ANNUAL AND CUMULATIVE INSTALLED WIND CAPACITY, 1997-2016 (GWEC 2016A)

More than 90 countries have commercial wind power installations with Asia, USA and Europe as the leading regions in terms of installed capacity. Approximately, half of the total annual installed capacity is in China, whereas the offshore industry mainly is in Europe. Forecasts indicate a steady growth in the future for emerging countries such as Latin America, Africa and Middle East (GWEC 2016a). The theoretical potential for wind is estimated at 1,700,000 TWh/yr (Rogner et al. 2000), which is way above the World's current energy demand. However, factors such as geography, technology economy and market conditions affect the realistic potential. Wiser et al. (2011) conclude that economical and institutional factors will be the largest constraint and that the technical potential is in the range of 23,400 to 162,000 TWh/year. As the technology develops, cost decreases and more policy measures and market incentives are introduced the technical potentials will increase (Krewitt et al. 2009). A range of scenarios have been developed to estimate the growth of the wind power industry all concluding that wind power will be central in the future energy scenarios with promising growth rates (GWEC 2016b).

5.1.2. TECHNOLOGY AND VALUE CHAIN

Wind turbines have, as mentioned, evolved from small scale, simple devices to industrial scale, sophisticated machines. Advancements have been realized in diagnostic control systems, design standards, manufacturing, operation and maintenance procedures. More than three decades of basic and applied research, ongoing cost reductions and government policies to expand the share of renewable energy have contributed to the industry's rapid development.

Basic design principles: Wind turbines typically start rotating, and thereby generating electrical power, at wind speeds of three to four m/s (cut-in speed). Most turbines stop extracting energy at speeds of 20-25 m/s (cut out speed) in order to prevent damage to the turbine's structural components (Wiser et al. 2011). Higher energy capture can be achieved through different design configurations such as higher wind speeds, higher generator capacity, longer rotor diameters, aerodynamic add-ons, taller towers, etc.

Turbine components and materials: Wind turbine configurations can differ significantly i.e. horizontal or vertical axis designs, rotor blades positioned upwind or downwind of the tower. Commercially available turbines have a horizontal axis design, where three blades are positioned upwind. A wind turbine can have upwards of 8,000 components (EWEA 2009a). Figure 5-2 and Table 5-1 depict the turbine components.

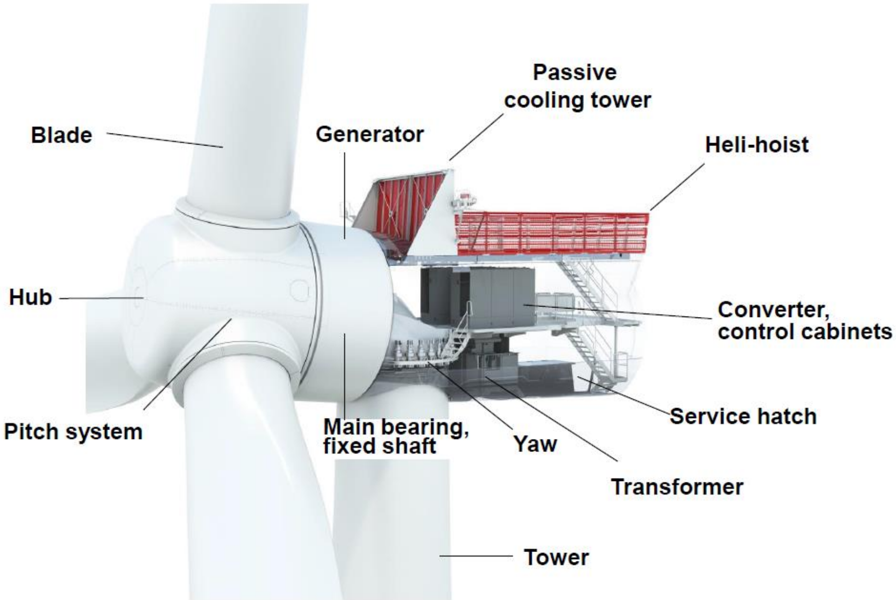

FIGURE 5-2. CROSS-SECTIONAL VIEW OF A WIND TURBINE

TABLE 5-1. DESCRIPTION OF WIND TURBINE COMPONENTS (ADAPTED FROM AUBREY 2007; GASCH & TWELE 2012; GOMEZ-BRICEÑO ET AL. 2012; JANSSEN ET AL. 2012)

Component	Description
Rotor	Consists of the rotor blades, aerodynamic break, hub and spinner and represents the heart of the turbine. The rotor blades are considered a critical component by manufacturers because they capture kinetic energy from the wind. They are made from fibre-reinforced plastics and new blades range in size from 30 to 80 m. Three blades are conventional but two bladed turbines also exist.
Drive train	Consists of the gearbox, generator, rotor shaft, bearings and brake. The power from the rotation of the wind turbine rotor is transferred to the generator through the drive train i.e. through the main shaft, the gearbox and the high speed shaft. These components transform the variable low speed rotational energy to higher speeds, needed for the generator. Iron and steel are the predominant materials. Some gearboxes have been replaced by direct drive mechanisms that improve efficiency and decrease maintenance costs. The generator converts mechanical energy into electrical energy. Most generators are made of steel and copper. Permanent magnets are used if there is a direct drive mechanism instead of a gearbox. Permanent magnets contain rare earth elements such as neodymium and dysprosium. Bearings are considered the Achilles heel of a wind turbine because they allow the components to smoothly operate. They are made of high strength steel and have bore diameters of between 100 and 700 mm. The shaft transmits rotational forces from the blades to the generator. The shaft is made of steel or iron. The nacelle is a lightweight fiberglass structure that contains most of the mechanical and electrical components and protects them from the external environment. Some are large enough to host a helicopter pad for technicians.
Supporting structure	Consists of the tower and foundation. The tower supports the nacelle. Towers are usually tubular in shape and made of steel but concrete and lattice structures are also commonly used. They can have heights of 160 m and normally account for 30 to 65% of the turbines overall weight. The foundation is a concrete base that is reinforced with steel bars to which the wind turbine is affixed.
Control system	Consists of electrical components that are used for the control and grid connection. The control system includes yaw, pitch, speed, and brake systems. These parts manage blade and turbine direction and speed to ensure optimal energy output and correct supply to the grid. Power converters transform the direct current from the generator to an alternating current for the power grid. Power converters are electronic devices composed of semiconducting elements.

Turbine size, capacity and lifetime: The average wind turbine size has significantly increased in the last three decades (Figure 5-3). Since the 1980s, wind turbine capacities have increased from 75 kW to 5 MW for onshore and from 3 to 9 MW and larger for offshore, where rotors are currently exceeding 164 m diameters and towers are surpassing 150 meter heights (GWEC 2016b). The trend is that the installed turbines are getting larger both onshore and offshore. (Navigant Research 2015). Commercial wind turbines are type-certified to safely withstand harsh environments for 20 years onshore, although they may last longer if installed in low turbulence regions. Since conditions at sea are less turbulent than on land, offshore turbines are type certified to last 25 to 30 years (EWEA 2009a).

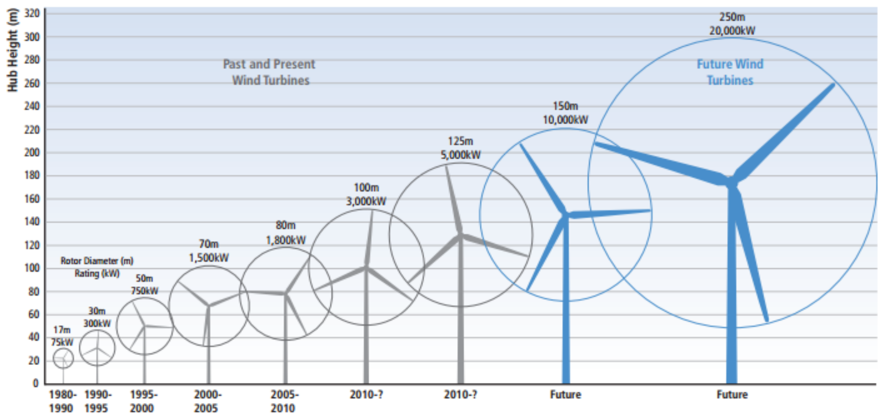

FIGURE 5-3. GROWTH IN SIZE OF MODERN, COMMERCIAL SCALED WIND TURBINES (WISER ET AL. 2011)

Costs: LCoE have been the main competition parameter for wind against conventional energy sources the last years. In regions with good resources wind are cost competitive with other energy sources (IEA 2010). The prices of onshore wind power have been in the range of 43 to 182 USD per MWh and 136 to 275 USD per MWh, which shows the variation throughout different locations (IEA 2015). The wind industry is focusing on improvements in the full life cycle to lower the costs with both incremental potentials as well as radical innovations such as floating turbines; higher altitude wind power machines; grid integration and electricity storage (Wiser et al. 2011). Capital costs account for 65 to 85% of the total expenditure for onshore and 30 to 50% for offshore (EWEA 2009a; IRENA 2012).

Value chain: At the end of 2013 the industry employed roughly 600,000 people and is expected to employ upwards of 2,200,000 million by 2030 (GWEC 2016b). Previously, a few major players dominated the industry but today it is composed of a network of diverse stakeholders that interact at all stages of a wind farms life cycle including suppliers, manufacturers, developers, owners, operators, etc. There are also a number of wind power consulting, research and certification organizations that assist at different stages of a wind power plants development.

There is a range of turbine manufacturers that dominate the industry with companies like Vestas, Siemens Gamesa Renewable Energy, Enercon (all EU), Goldwind, Sinovel (China) and General Electric (US) as the major ones, but also a large group of smaller manufacturers. Only a few – Vestas, Siemens Gamesa Renewable Energy, General Electric and Senvion – have entered the offshore market.

5.1.3. WIND POWER AND ITS ENVIRONMENTAL AND SOCIAL ASPECTS

There are a number of environmental and social aspects of wind power that can be considered as either beneficial or disadvantageous. Estimating these benefits and impacts can be difficult, especially when considering a life cycle perspective or comparing them against other energy sources. Evaluations are highly dependent on the assumptions that are made (system boundaries).

BENEFITS

GWEC (2016a) sees wind power as an important solution to climate change, energy security and price stability and credits the industry as a driver of new industries and employment. Benefits of wind power include, but are not limited to:

Displacement of fossil fuels: Wind power boasts a number of environmental benefits, but the most obvious relates to the displacement of fossil based power, and thereby greenhouse gases and other emissions during operation. Furthermore, the operational stage does not require fuel, which is typically obtained through intensive mining or drilling methods (e.g. coal or uranium) and avoids the production of waste by products (e.g. oil sands tailings ponds or radioactive waste). GWEC (2016b) estimates average carbon savings of 600 gCO2/kWh by using wind compared to fossils.

Low carbon footprint: LCAs according to ISO 14040 and 14044 standards are commonly used to evaluate the positive and negative contributions from a turbine/wind farm across its life cycle stages. They provide a comprehensible and consist way to evaluate the impacts at different life cycle stages of a wind farm e.g. material extraction, manufacturing, construction, assembly and installation, operation and service, end of service and dismantling (EWEA 2009b). Some have been peer reviewed and scientifically published (Ardente et al. 2008; Garrett & Rønde 2013; Guezuraga et al. 2012; Haapala & Prempreeda 2014; Martínez et al. 2009; Raadal et al. 2014; Schleisner 2000; Wagner & Mathur 2013; Weinnzettel et al. 2009), while others have been performed by manufacturers or developers (Gamesa 2013, 2014; Siemens Wind Power 2015; Vattenfall 2014, 2016; Vestas 2006, 2011a, 2011b, 2014). The aspects can be assessed based on a number of impact categories (e.g. climate change, resource use, land use, toxicity, etc.) but most wind related LCAs use climate change in terms of CO2 equivalents per unit (1 kWh) electricity generated which enables a comparison between other energy sources. The majority of greenhouse gas estimates range between three and 20 grams CO2 eq. per kWh, but older studies also show higher values up to 45 CO_2 eq. per kWh (Dolan & Heath 2012; Wiser et al. 2011).

Short energy payback: The energy payback time is the common reference used for wind farms, representing the operational time needed to produce the equivalent amount of energy that is required to pay off the wind farms life cycle impacts (e.g. manufacturing, installation, servicing and decommissioning). (Wiser et al. 2011) reviewed 20 studies and found that the median energy payback time was 5.4 months. Different turbine designs and assumptions made explains variability in the results.

Water preservation and conservation: (OECD 2013) informs that future climate change and population growth will intensify water scarcity and that by 2050, 40% of the world's population will encounter some form of water stress. Conventional power plants (e.g. thermal and nuclear) require high amounts of water for cooling purposes, and represent the largest consumer of water in the EU (44%). In contrast, wind power essentially utilizes no water thereby contributing to its conservation and preservation (EWEA 2014c).

Net social benefits: Environmental LCAs and life cycle costing methods have become well established in both academia and industry. More recently, social LCAs (S-LCAs) have been introduced which add an extra dimension to the impact analysis domain and provide valuable information for companies who seek to produce or purchase responsibly. S-LCAs determine potential social and socio-economic aspects of a product's value chain including the benefits and impacts to the workers, value chain actors, local communities, consumers and broader society. The net benefits of wind power tend to be underestimated by not including impacts such as those included in S-LCAs or related methodologies.

There has been a lot of social research on wind power i.e. employment benefits, stakeholder engagement, local nuisance impacts like visual impacts, noise, etc. to date but only three studies have applied the S-LCA or similar methodologies to wind power specifically. Vattenfall (has included a S-LCA as an appendix to its EPD for electricity from their Nordic wind farms based on the Guidelines for Social Life Cycle Assessment of Products (UNEP/SETAC, 2009) and the Handbook for Product Social Impact Assessment (Roundtable for Product Social Metrics 2014). Similarly, Scottish and Southern Energy (SSE) measured the social and economic implications of the extension to the Clyde wind farm using the Total Impact Measurement and Management methodology. Including socio-economic measures in the cost of energy has been proposed by Siemens Wind Power to reflect the complete cost-benefit ratio of the various energy technologies (Siemens 2016d). Society's Cost of Electricity

(SCOE) is an alternative evaluation model, which includes factors such as subsidies, employment effects, transmission costs, social effects, variability costs, geopolitical risk and environmental impacts. This assessment has shown to in favour of the renewable energy sources compared to fossil fuels.

DISADVANTAGES

Wind power has been associated with some potential environmental and social impacts. A number of authors provide a full picture overview of these impacts including Dai et al. (2015), EWEA (2009) and Saidur et al. (2011). Topical areas of interest include, but are not limited to:

Wind variability: The variability of wind affects the operation, and thereby emissions, of conventional based energy sources. The fluctuations in wind power generation causes part-loading of fossil based energy sources which reduces the power plants efficiency compared to a full-loading plant. An impact LCAs seldom account for.

Impacts to flora and fauna: Siting a wind farm has impacts on the area of construction. Broader planning and siting requirements i.e. environmental impact assessments, have improved because of these concerns.

Some of the most publicized concerns among communities are collisions with birds and bats and the impacts to benthic zones and fisheries. Wind turbines can kill birds and bats and negatively affect marine life. Impacts will vary based on regional characteristics, migration periods and wind farm characteristics.

A study by NRC (2007) found that bird mortality rates ranged between 0.95 and 11.67 deaths annually per MW. Comparatively, bat mortality rates ranged between 0.8 and 41.1. Siting wind farms away from high bird and bat population densities and altering turbine operations under certain conditions are two prospective mitigations (Arnett et al. 2011; Baerwald et al. 2009), which is also integrated in some turbines today with e.g. Bat-systems that can shut down the operation of the turbine if bats are detected. However, when put in the context of other fatalities caused by anthropogenic causes e.g. buildings, windows, vehicles, other energy sources etc., the estimated cumulative impact on birds and bats is minimal (National Wind 2010; Wiser et al. 2011).

Empirical research on offshore impacts is also not as extensive compared to onshore and has so far, mainly been conducted in northern European (Leonhard et al. 2011; Lindeboom et al. 2011; Mann & Teilmann 2013). A study by Bergström et al. (2014) indicates some disturbances i.e. noise and vibration, during the installation and decommission stages due to drilling and dredging activities on the sea floor. They indicate that fish and marine mammals return soon after activities cease. During the operative stage, habitat gain typically increases species populations, which can have both positive and negative effects. Support structures create an artificial reef effect, which has been used to improve biodiversity (Mikkelsen et al. 2013), tourism (Wilhelmsson et al. 1998) or fisheries (Seaman 2007). However, the offshore support structures can also introduce non-indigenous species (Bulleri & Airoldi 2005). Increases in vessel traffic during installation and service stages can also contribute to noise and the introduction of invasive species. In order to minimize these impacts, ecological reports are needed, prior to offshore installation and commissioning (Mangi & Mangi 2013).

Socio-environmental impacts: There are also a number of socio-environmental impacts, which are commonly referred to as nuisances e.g. impacts on proximate communities, aviation, shipping and communication. Wind farms encompass large land areas (5 to 10 MW per km2) that could be used for other purposes (Wiser et al. 2011). Further, individual turbines and wind farm sizes are growing in scale and are commonly cited at higher elevations. Visual impacts are thus one commonly referenced concern among communities (Ledec et al. 2011). This aspect has resultantly been included as a point in siting procedures, requiring photos and the implications on property value to be noted. Noise and shadow flicker are other concerns frequently raised. Standards and regional legislation have been introduced to indicate permissible acoustic levels while control systems and different tip shapes have been designed to reduce shadow and noise effects. Despite these concerns, a number of studies find that the general public accepts wind power (Klick 2010; Poumadére et al. 2011; Warren et al. 2005). Addressing these concerns early in the siting and planning phases through participatory and transparent methods is of utmost importance to a wind projects success (Gross 2007; McLaren Loring 2007; Wolsink 2007). Other studies have indicated that local ownership and other benefit sharing arrangements improve the social acceptability of wind projects and speed up the planning process (Cowell et al. 2011; Gross 2007; Ledec et al. 2011; Wolsink 2007).

As described, the wind industry has experienced a significant increase in installed capacity, turbine size in recent years. The industry has moved from small utility-scale application to a highly industrialised industry, where consolidation is taking place in the value chain. The wind power industry was born out of the desire for low-carbon energy production technologies, but it is currently facing challenges related to cost of energy as well as social acceptance.

5.2. SIEMENS' PRODUCT DESIGN AND ENVIRONMENTAL PRACTICES

This section of the chapter is divided by the corporate Siemens AG and the wind power Division which enables an analysis between the two.

5.2.1. ORGANIZATIONAL HISTORY AND STRUCTURE

This section briefly describes the organizational history and structure of both Siemens AG and the Wind Power Division. The vision and mission of both organizations are also explained respectively.

SIEMENS AG

Siemens AG is a multinational conglomerate with headquarters in Berlin and Munich. It was founded in 1847 by two men as the "Telegraphen-Bauanstalt von Siemens & Halske" company. Today it is one of the largest technology companies focusing on electrification, automation and digitalization (Siemens 2017b). Siemens AG frames itself in the following way:

> *"For over 165 years, Siemens has stood for engineering excellence and innovation, for quality and reliability, for human creativity and drive, for stability and financial solidity and, last but not least, for good corporate citizenship"* (Siemens 2015a, p.4).

In fiscal year 2016, the company employed 351,000 employees globally in over 200 countries. At the same time, it generated revenues from continuing operations of €79.6 billion and a net income of €5.6 billion. SWP accounted for 7% of the SAG revenue (Siemens 2017b).

As of 2016, Siemens AG consisted of ten Divisions including SWP. The Divisions are shown in Figure 5-4 in relation to the portfolio and megatrends. The managing board and corporate functions are also depicted. Today SWP and Healthineers are separately managed.

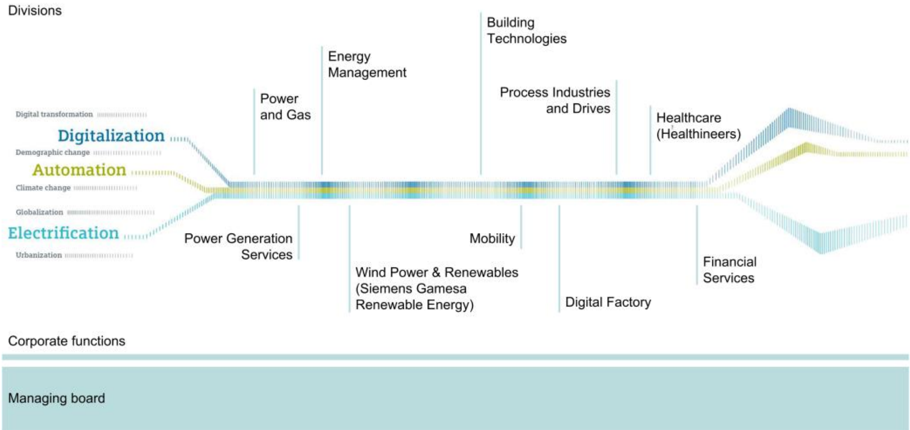

FIGURE 5-4. ORGANIZATIONAL STRUCTURE IN SIEMENS AS OF 2016 INCLUDING DIVISIONS ALONG PORTFOLIO (SIEMENS 2017d)

In 2014 the company launched a five year company-wide strategy (Vision 2020) that is based on three core elements, its: 1) mission, 2) vision related to ownership culture, and 3) strategy. Siemens' mission, or what it calls "path" to self-understanding and how it defines its aspirations:

> *"We make real what matters, by setting the benchmark in the way we electrify, automate and digitalize the world around us. Ingenuity drives us and what we create is yours. Together we deliver"*

Regarding its vision, a lived ownership culture implies that every employee takes personal responsibility for the company's success, and this is said to be the engine of the company:

> *"Always act as if it were your own company"*

Vision 2020 is accompanies by a strategy containing seven goals and a positioning within electrification, automation and digitalization. This is based on long term trends that define the company's markets and stakeholder requirements:

> *"Vision 2020 defines a concept that will enable us to consistently occupy attractive growth fields, sustainably strengthen our core business and outpace our competitors in efficiency and performance"* (Siemens 2014a).

Siemens held a strong presence as an official partner at 2015 COP22 event in Morocco. There the company launched a new brand "Ingenuity for Life" that was also out of response to both the new Siemens strategy (Vision 2020) and the 200th birthday of its founder Werner von Siemens. The new claim is:

> *"Ingenuity" stands for engineering, genius and innovation. For us, it also stands for unity: "we are united in our efforts, and we are committed to partnering with our customers"*
>
> *"For life" relates to our role in the world: "to make real what matters".*
>
> *"Ingenuity for life" is therefore our unrelenting drive and promise to create value for customers, employees and society* (Siemens 2017e).

Siemens' core values are *responsible, excellent* and *innovative* and have been the same since the days of Werner von Siemens. When combined, they create ingenuity for life. Joe Kaeser, Siemens President and CEO states:

> *"For me, "Ingenuity for Life" means that we will always place our innovative strength at the service of society. And we intend to live up to this aspiration, today and in the future"* (Siemens 2016b).

SIEMENS WIND POWER

The history of SWP dates back to 1980, with the foundation of Danregn and its legacy progresses through with the acquisition by Siemens in 2004 to today's merger with Gamesa Technology Corporation. Below I describe the technological developments, key milestones and the expansion of the company that are summarized in Figure 5-5.

In 1980 the Danish company Danregn, known for its irrigation systems, began developing wind turbines based on a new market demand in response of the 1970s international energy crisis. Danregn Vindkraft's first wind turbines had generator powers of 20 to 30 kW, rotor diameters of 10 meters and tower heights of 18 meters. The company changed its name in 1983 to BONUS Energy due to the fact that Danregn could not be pronounced in English (Mægaard et al. 2016). In 1982 they delivered their first six turbines to Oak Creek in Tehachapi, California. 1991 marked an important milestone for us with the creation of the world's first offshore wind farm, Vindeby that featured 11 units of the 450 kW BONUS turbines. The original turbines are still operating today with a total capacity of 4.95 MW (ENS 2017).

Continuing the development of its product portfolio, BONUS Energy managed to break the 1 MW mark in 1997 and the 2 MW in 1998. Twenty 2 MW turbines were installed in the Middelgrunden Offshore Wind Farm, close to Copenhagen in 2001 (ENS 2017) and the number of employees had increased from 350 to 400 (Mægaard et al. 2016). Prior to 2002, all major components were sub-contracted until BONUS Energy launched its own blade factory in Aalborg (Ing 2002). In 2004 Siemens took over BONUS Energy as its first time entrance into the wind energy business (Siemens 2004). After the acquisition, SWP grew exponentially. Between 2004 and 2011, employee numbers grew from 800 to 7,800, of which 5,200 were in Denmark and 1,000 in Germany. A number of regional sales and project management offices as well as world class production facilities were established globally. In 2009, SWP experienced a number of highlights: a new turbine design using direct drive and permanent magnets began replacing geared turbines, which would have large implications for the offshore market and the environment, claiming half the components and a lower nacelle weight (Buck 2013). The company also expanded its cooperation with DONG Energy by entering an agreement to deliver up to 500 offshore turbines with a total capacity of 1,800 MW (Siemens 2009a) and with Statoil Hydro by installing the world's first large scale floating wind turbine at Hywind where it was tested and agreed the park would be expanded (Siemens 2009b).

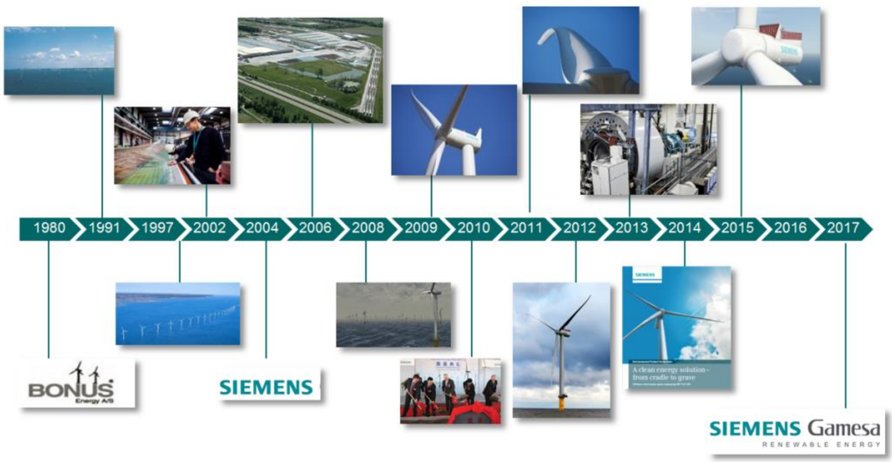

FIGURE 5-5. HISTORY OF SIEMENS WIND POWER

Continuing the development of its product portfolio, BONUS Energy managed to break the 1 MW mark in 1997 and the 2 MW in 1998. Twenty 2 MW turbines were installed in the Middelgrunden Offshore Wind Farm, close to Copenhagen in 2001 (ENS 2017) and the number of employees had increased from 350 to 400 (Mægaard et al. 2016). Prior to 2002, all major components were sub-contracted until BONUS Energy launched its own blade factory in Aalborg (Ing 2002). In 2004 Siemens took over BONUS Energy as its first time entrance into the wind energy business (Siemens 2004). After the acquisition, SWP grew exponentially. Between 2004 and

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In 2010 SWP acquired 49% of A2SEA, an offshore wind farm installation company (Siemens 2010a) which it later sold in 2017. Siemens´ goal with its commitment in A2SEA was to advance the industrialization of offshore wind power. The same year, it was announced SWP would become one of nine Divisions within Siemens and the headquarters were relocated from Brande, Denmark to Hamburg, Germany. The company also expanded its operations by establishing a service business unit to handle the growth in maintenance and upgrade services. SWP introduced a redesigned blade, the quantum blade, in 2011 with revised root and tip sections and a lighter design than its previous versions which reduced noise levels to only 105 decibels, which is among the quietest on the market (Siemens 2017f). The first 6 MW prototype was also installed at the test site at Høvsøre, Denmark which included a 75 meter blade (Siemens 2011). On May 12th, 2012, Siemens' SWT-6.0-120 offshore wind turbine prototype produced 144,000 kWh of electricity representing a new record for wind turbines in Denmark within a 24-hour period, and equivalent to the electricity consumption of approximately 10,000 households in the same period (Siemens 2012a).

Another milestone was the 2013 inauguration of the world's largest offshore wind farm, London Array, with a combined capacity of 630 MW. It set a world record in 2015 by generating 369 GWh during the month of December (Weston 2016). In 2014 SWP continued its path of establishing itself as one of the largest companies in the wind energy industry. According to MAKE and BTM, Siemens Wind Power ranked 1st and 2nd respectively (Staff 2015; Recharge News 2015). It was also the year, where EPDs for the entire product portfolio were published (Siemens Wind Power 2015). Installation of a 7 MW prototype at Østerild Test Center occurred in 2015, which was an upgrade of the 6 MW platform including upgraded magnets in the generator (Siemens 2015b). The 7 MW turbine was ranked as the world's best offshore turbine by Wind Power Monthly (de Vries 2015a) and the 3MW DD as the best in its category this same year (de Vries 2015b). An 8 MW was also announced for production. 2017 marked the end of legacy SWP as the company was carved out of Siemens and merged with Gamesa Technology Corporate to form a "leader in the renewable energy industry" and "a big four of OEMs" with a combined installed capacity of 75

GW, installations in 90+ countries, 27,000 employees and an order backlog of €21 billion (Weston 2017; Siemens Gamesa Renewable Energy 2017).

Overall, SWP has undergone several organizational changes within this research timeframe, mainly due to its rapid organizational growth which is a reflection of the industry's growth. These changes have had significant effects on the organizational structure and products as well as its environmental and product development practices. Figures 5-6 and 5-7 below illustrate this development, both in terms of increasing product size and installed MW per year.

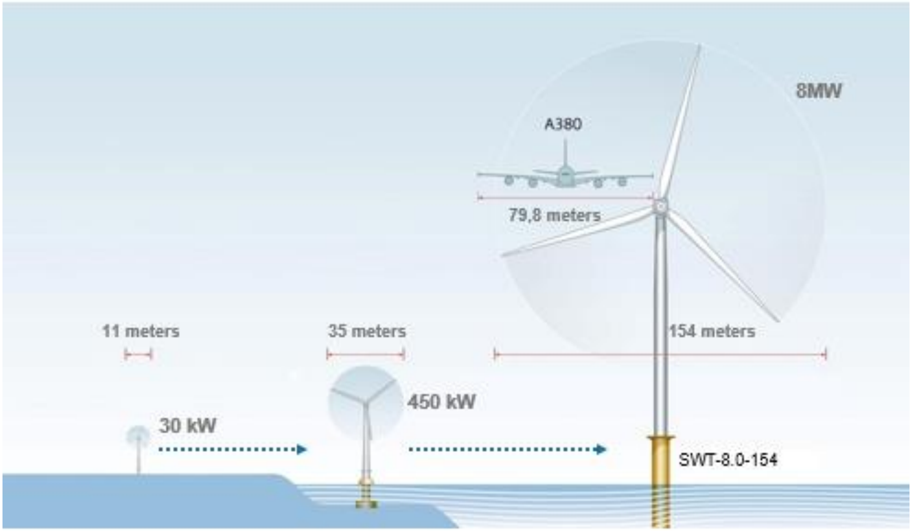

FIGURE 5-6. INCREASING PRODUCT SIZE: 30 TO 8,000 KW BETWEEN 1980-2017 (SIEMENS WIND POWER 2016c)

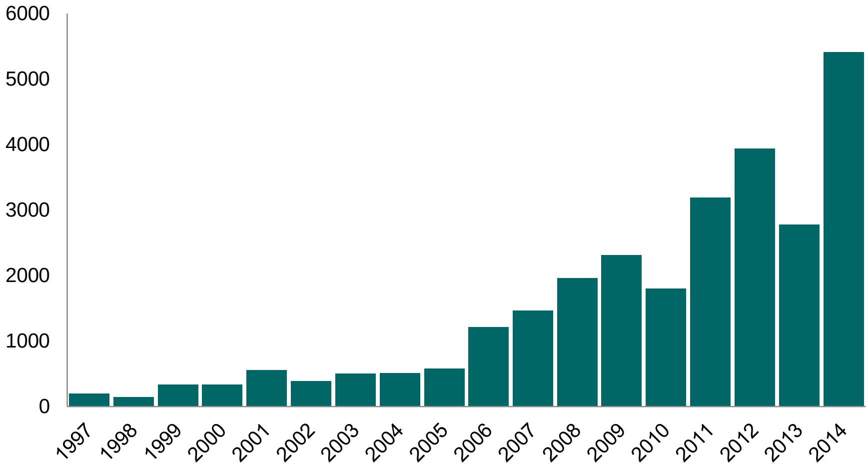

FIGURE 5-7. INCREASING TURBINES INSTALLED: 300 TO 5,000 MW BETWEEN 1990 AND 2014 (SIEMENS WIND POWER 2016c)

SWP is a matrix organization divided into the three market units: onshore, offshore and service (Figure 5-8). The market units are then supported by a range of Division functions that run across the market units and act as governance. This includes the EHS Division function where the PhD project is situated. In 2016, Siemens had approximately 12,800 employees, a number one market position in offshore and a number four market position in global installations. The company had an installed base of over 16,800 turbines in 40 countries with approximately 32,400 MW of capacity. In 2015 alone, the SWP installed almost 2,000 turbines accounting for roughly 5.6 GW of capacity (Siemens Wind Power 2016a).

The mission at SWP describes who "we" are and what "we" are doing:

> *"Engineering the Wind: We are here to make efficient wind turbines that interact with nature to produce clean, renewable energy."*

The vision at SWP represents the company's direction and future focus:

> *"We want to be the Best@Wind - this is our ambition. Best@Wind means we want to be preferred because of our quality, reliability, innovation and responsibility. That is our way to achieve sustainable success and a long term profit."*

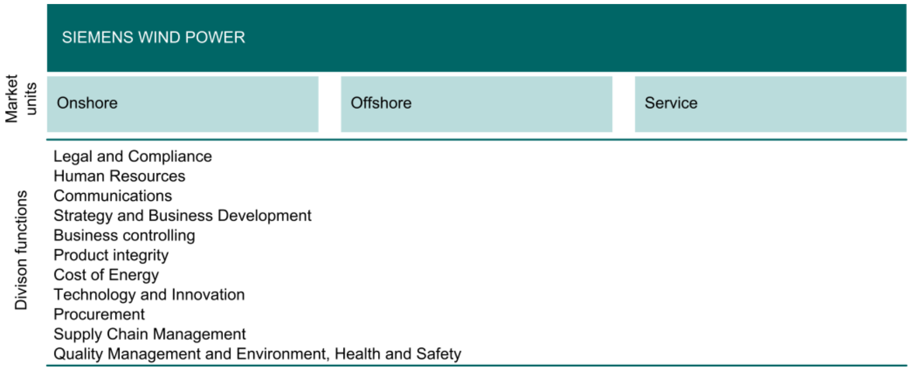

FIGURE 5-8. ORGANIZATIONAL STRUCTURE IN SIEMENS WIND POWER AS OF 2016

During 2014, a number of SWP's challenges had become more pressing in an increasingly aggressive market. Customers' portfolio demands were changing, levelized energy costs were a constant focus and collaboration models with suppliers were in need of revisions for more long term partnerships. Markus Tacke, CEO was quoted as saying:

> *"We're facing a lot of challenges and we don't have the luxury of picking just one to solve, or of tackling them one at a time. They're all coming at us at once."*

The Wind 2020 strategy was developed as a result and four "Must Win Battles" were identified as levers to help bring SWP back to profitability. These included: cost-competitiveness, a competitive product portfolio, supplier quality improvements to avoid non-conformance and warranty costs (Zero-Defect Culture), and a leadership culture that is based on ownership, empowerment and trust (Leadership@Wind). The latter is a direct extension of "ownership culture" from Siemens AG's Vision 2020. Further, the Must Win Battles received priority to resources such as time, money and efforts (Siemens 2014c).

5.2.2. PRODUCT DEVELOPMENT PRACTICES

This section briefly describes the product development practices of Siemens AG and the Wind Power Division. The product portfolios as well as the product development process are described.

SIEMENS AG

Some of the key product innovations over Siemens' 168 years of operation can be seen in Figure 5-9. As shown, the company has continually adjusted its product portfolio e.g. the pointer telegraph (1847), the world's first locomotive (1879), the world's first electric streetcar (1881) are some examples from a long list (Siemens 2017b). Today, Siemens' product portfolio and innovations reflect a number of megatrends spanning from digitalization, demographic change, climate change, urbanization and globalization. The company further positions its portfolio around three key areas: electrification, automation and digitalization.

Through its portfolio of products and services, Siemens claims to embrace the technological shifts needed to address megatrends such as climate change and resource scarcity (cf. IPAT equation in 3.1.1). In 2008, Siemens launched its first Environmental Portfolio which consisted of a bundled set of products and solutions that directly contribute to energy efficiency and renewable energies as a testament to this claim. The company hopes its brand is globally recognized for sustainable, forward-looking technologies that can change the world for the better and Improving the competitive position of its customers through primarily energy efficiency and the deployment of renewables (Siemens 2012b). Products must qualify for the portfolio by meeting clear criteria which are based on LCAs, among other parameters. This includes newly developed products, components or services as well as existing ones that have been improved. Siemens product portfolio consists of mostly investment goods which last many decades, so energy and resource efficiency during the use phase is one of the main levers for supporting Siemens' customers in reducing their operational as well as total cost of ownership (Pfitzner & Lutz 2015).

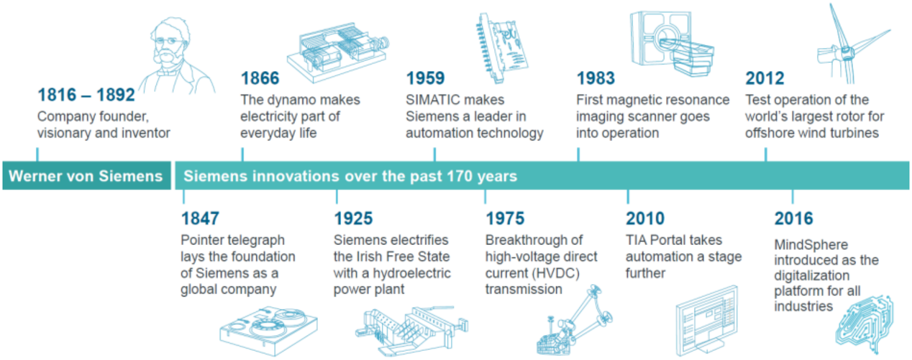

FIGURE 5-9. SIEMENS PRODUCT PORTFOLIO (SIEMENS 2017d)

Since its launch, the company has reported annually on the environmental benefits of its products including how much CO_2 is avoided for the customer and how much revenue is generated from these products. For example, in 2016 Siemens' products in the Environmental Portfolio enabled customers globally to reduce their CO_2 by 521 million metric tons. This is based on a cumulative figure, being products installed in previous years or still in use and corresponds to roughly 60% of Germany's annual CO_2 emissions. In 2016 alone, the number was 60 million metric tons. Further, the Environmental Portfolio revenue in 2016 amounted to €36.3 billion or 46% of Siemens' revenue from continuing operations (Siemens 2017b; Siemens 2017k).

At the end of 2016, Siemens established a new unit to foster disruptive ideas more vigorously and to accelerate the development of new innovations and technologies. They called it Next47 as a reference to the year Siemens was founded (1847) and will use it to incubate Siemens' next generation of start-up activities (next47 2017). Some of the innovation fields set forth include: decentralized electrification (energiewende 2.0), artificial intelligence, autonomous machines, connected e-mobility and blockchain applications (next47 2016). von Karczewski & Zistl (2017) explain that Siemens has begun adopting a more positive attitude to the concept of open innovation. There quote below also relates well with the communities of practice concept related to brokering across knowledge boundaries (cf. 3.3).

> *"A great deal of momentum comes from in-house competitions for new ideas and collaborations between Siemens and top international universities and non-university research institutions.* […] *Networking, thinking beyond stereotypes, and talking to, making suggestions to, and supporting people in other departments is how innovations come about at Siemens"* (p.368).

SIEMENS WIND POWER

SWP operates worldwide to produce and install wind turbines as well as to provide global service operations to installed turbines. The current product portfolio includes four platforms and multiple product variations (Figure 5-10). This categorization allows for standardized components such as rotors, generators, towers and hubs to be used in the various wind turbines. Components can be adapted to specific customer requirements and site conditions, where conditions can range from high to low wind areas, noise restricted areas or locations with severe weather patterns. The service offerings both in combination with turbine sales and as a stand-alone concept are not reflected in Figure 5-10 as they were out of the research scope but range from basic scheduled visits to complex service programs including remote diagnostic services, performance warranties and logistic solutions. The full range of products and services in SWP's portfolio contribute to Siemens' Environmental Portfolio due to their contributions to climate change.

Product platforms	Onshore geared	Onshore direct drive	Offshore geared	Offshore direct drive
	SWT-2.3-101/108	SWT-3.0-101/108/113	SWT-3.6-120	SWT-6.0-154
	SWT-2.5-120	SWT-3.2-101/108/113	SWT-4.0-120/130	SWT-7.0-154
		SWT-3.3-130		SWT-8.0-154
		SWT-3.4-108		

FIGURE 5-10. OVERVIEW OF THE PLATFORMS AND PRODUCT OFFERINGS AS OF 2016

Siemens is a very formalized and process oriented company. There are two central platforms (Process House and Document House) which act as a database for the management system and contain various process flow diagrams as well as global and local procedures and instructions. Therein, three core business processes are defined for SWP (Figure 5-11) which include: customer relationship management, supply chain management and product lifecycle management. Product development is to some degree related to all three core business processes but the traditional R&D and stage gate activities fall within the latter process of product lifecycle management (PLM).

The PLM includes the strategic planning, design and development, monitoring and phase-out activities of the whole product life cycle. It is shown in greater detail in Figure 5-12. Its purpose is to increase customer value and profit through the development and delivery of products and does so by combining various people, processes, information and tools. The product development process (PDP) also falls within the PLM process and is characterized by a formal stage-gate model where anything ranging from components, to factories, to manuals or to supplier relations can be designed. The PDP is also commonly referred to as “PDP@Wind”. Cross functional collaboration is a central pillar as described in SWP’s PDP Handbook:

> *“Teamwork across domains is a central pillar of the PDP* […] *The PDP enables cross functional alignment of goals within project teams, facilitates informed business decisions and ensures overall product quality, manufacturability, supportability, marketability and regulatory compliance”* (Siemens Wind Power 2016b, p.3)

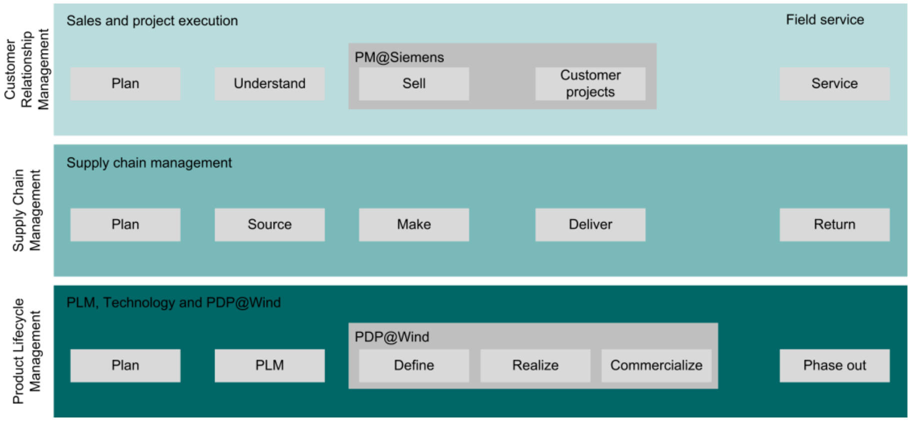

FIGURE 5-11. CORE BUSINESS PROCESSES AT SWP

Coincidentally at the onset of this PhD, SWP was beginning to restructure its R&D and Technology function and PDP. Restructuring had the goals to better formalize and control R&D and project activities as well as better respond to future portfolio demands and capture learnings between projects. For this reason, my research took point of departure in the PDP and the various interlinkages with primarily the PLM, Technology and Project Management functions. The PLM function oversees customer benefits and the portfolio development and maintenance in comparison to the Technology function which focuses on the design of products and technologies and the Project Management function which handles all the project related tasks such as documentation, coordination, etc.

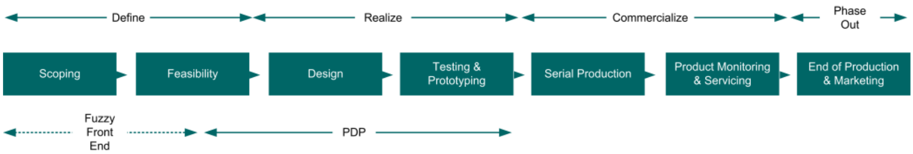

FIGURE 5-12. OVERVIEW OF SWP'S PRODUCT LIFECYCLE MANAGEMENT PROCESS

Over the project duration, the PDP had more than one revision a year due to the changing nature of the organization and the increasing demands from both internal functions and customers. In Chapter 6 and 7, the product development process is further described and analysed in terms of stakeholder involvement and environmental practices.

Existing design activities are highly tantamount with environmental improvements in SWP. Sustainable innovations are frequently emerging but based on different intentions such as to reduce levelized energy costs, to maintain a strong market position, etc. A few examples are listed below in Table 5-2 to illustrate this:

TABLE 5-2. SUSTAINABLE INNOVATIONS IN SIEMENS WIND POWER

Sustainable innovation	Description
6 MW direct drive	The introduction of this turbine model using permanent magnets boasted a resource efficient and lightweight design with 50% fewer moving parts which results in a safer working environment for technicians and reduced frequency between repairs and service visits.
Offshore direct drive platform	The design evolution from the 6 to 8 MW turbine required minimal structural changes but increased the annual energy production by 20% and respectively reduced the energy payback from 9.5 to 7.6 months.
Biomimicry principles	Biomimicry principles have been applied to reducing onshore turbine's noise and increasing energy output first in 2002 based on dinosaur tail's and then based on the structure of owl's feathers where a serrated structure was placed on the trailing edge of the rotor blade (Siemens 2016c).
Noise reductions during installation	Also related to noise reductions, offshore installations can apply two methods to reduce noise from traditional pile driving into the sea bed. The "bubble curtain" is the first option that uses two hoses that are inflated around the pile to be installed. A compressor pumps the hoses with air so the bubble ascends and reduces noise emissions. The "hydro sound damper" is the second method that resembles a fishing net wrapped around a pile that is filled with balloons and foam materials to absorb installation sounds.
Wildlife conservation	Turbines can be equipped with special control features and deterrent devices to prevent birds and bats from intersecting.
Magnet optimization	In collaboration with our suppliers, SWP developed a new method for developing the permanent magnets which improved the material use during manufacturing. Further engineers have been working to reduce and even eliminate heavy-rare earth elements (HREE) such as dysprosium or terbium (Pavel et al. 2017)
RoRo installation vessels	The Roll-on-Roll-off (RoRo) features a large bow door and retractable roof for easy loading. It can also carry up to nine tower sections which means savings of up to 15-20 percent in logistics compared to existing transport methods (Siemens 2015c).
Service operation vehicles	Service operation vehicles (SOVs) optimize the operation and maintenance phase for far-from-shore wind farms. The vessels are part floating hotels, part floating warehouses and when fully equipped, they are capable of remaining offshore at their respective wind farms for up to one month. Further a hydraulic walk-to-work gangway system allows technicians to safely access wind turbines in extreme weather conditions (Siemens 2015d).
Lifetime extension	The lifetime of the turbine has been extended from 20 to 25 years and there are a number of services available in order to maintain and extend the turbines lifetime.

In 2014, the concept of a society's social cost of electricity (SCoE) emerged at SWP. It is an alternative evaluation model from the LCoE debate, and expands to include additional costs borne by society such as subsidies, employment effects, transmission costs, social effects, variability costs, geopolitical risks and environmental impacts. Take for example the geopolitical risks that aren't factored into the LCoE for fossil or nuclear power sources. When social values are factored into the cost of wind power comparatively with other technologies, the positive aspects related to increasing the deployment of renewables such as wind are strongly emphasized (Figure 5-13) (Siemens Wind Power 2016d).

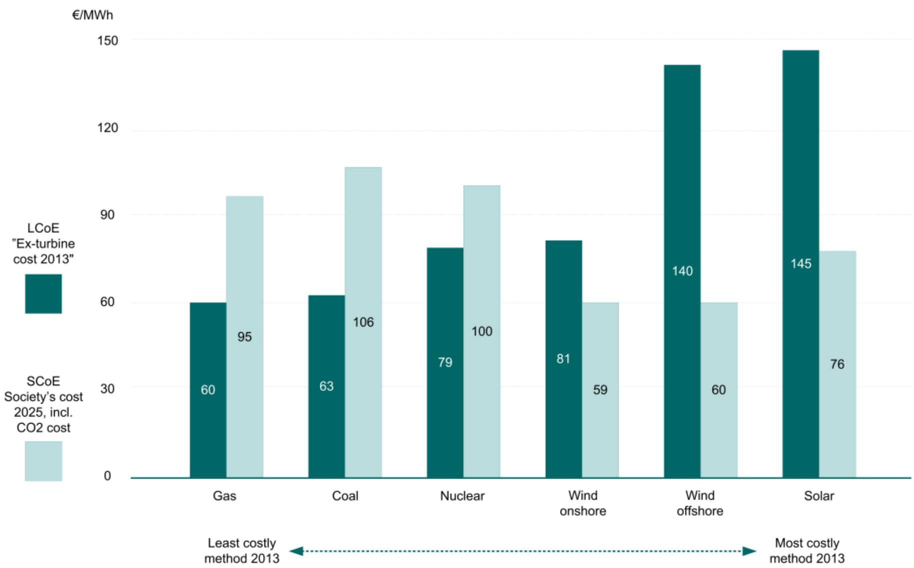

FIGURE 5-13. ESTIMATING THE TRUST COST OF ELECTRICITY (€/MWH) (SIEMENS 2016d)

5.2.3. ENVIRONMENTAL PRACTICES

This section outlines the environmental practices of both Siemens AG and the Wind Power Division. The EHS policy framework, strategic EHS programs and scope of product related environmental activities are also illustrated.

SIEMENS AG

EHS and Sustainability topics have a central position in Siemens AG and are an integrated part of Siemens' strategy. In an interview about this year's UN World Environment Day theme "connecting people with nature", Klaus Luetzenkirchen, head of the Corporate Environmental Protection Department, is quoted saying:

> *"It is especially important for large and globally operating company such as Siemens to be a role model. It is up to us to set an example, because we have a great responsibility to our employees and the locations where we are active. This year's motto is a good opportunity to get back to nature! Because it is our most valuable asset. Nature gives us the resources needed for our products, moreover an intact environment is essential for the health of our employees"* (Siemens 2017g).

There are a number of internal guidelines that establish clear rules such as business conduct guidelines, code of ethics, principles of diversity, EHS policy, supplier code of conduct, etc. (Siemens 2017h). Two corporate units oversee EHS and Sustainability topics at Siemens: Corporate EHS and Corporate Sustainability. Their scope of activities are briefly compared below.

Corporate EHS oversees the EHS management system including uniform policies, standards and programs, companywide targets and internal reporting. Their primary focuses are to: define the basic structure of the EHS organization, represent the basic requirements for all areas of the business, and facilitate cooperation between the various Divisions in the area of EHS. The EHS policy framework is composed of a mandatory set of normative documents, including the "EHS Principles", "Appendices" and "EHS Standards". Additionally they are further divided into environmental protection, health management, and safety topics and corresponding specific programs.

There are four programs governed by Corporate EHS (Figure 5-14) that were revamped in 2015 in line with Vision 2020 and are expected to run until 2020. They include:

1. "Serve the Environment" for industrial environmental protection.
2. "Product Eco Excellence" for product related environmental protection.
3. "Zero Harm Culture@Siemens" for safety.
4. "Healthy@Siemens" for health management.

This research was positioned within the "Product Eco Excellence" program but had strong correlations to the "Serve the Environment" program. The mandatory *Siemens Norm 36350: Environmental Compatible Product Design* which served as the foundation for my research was also one of environmental standards mandated by Corporate EHS. The norm had to be simplified and adapted to the specific context of SWP in order to make it operational (cf. Chapter 7 and Appendix B).

FIGURE 5-14. CORPORATE EHS FOCUS AREAS AND CORRESPONDING PROGRAMS

Corporate Sustainability provides corporate governance on sustainability topics divided into three areas: Environment, People and Society and Responsible Business Practices (Figure 5-15). They are more of an umbrella organization that creates links between other corporate functions with Siemens AG such as Corporate EHS, Corporate Supply Chain and Procurement, Corporate Human Resources, etc. The group oversees marketing materials, annual reports, sustainability indices and the environmental portfolio and also coordinates sustainability oriented programs, two of which are described below: “Business to Society” and the carbon neutral program.

Environment	People and society	Responsible business practices
Decarbonization	Health management	Sustainable supply chain
Conservation of resources	Safety	Compliance
Product stewardship	Diversity	Human rights
	Education	
	Corporate citizenship	
	Arts and culture	

FIGURE 5-15. CORPORATE SUSTAINABILITY FOCUS AREAS

There is also the Siemens Sustainability Board that is chaired by the Chief Sustainability Officer who is also a member of the Managing Board. Its members consist of representatives from the Managing Board, Divisions, countries and corporate functions. It meets regularly to direct sustainability activities as part of the corporate strategy (Siemens 2017b).

In 2014, a materiality matrix was conducted and the results were used to define twelve sustainability principles which are oriented around the 3P’s (cf. 3.1.2) and outlined below in Figure 5-16. They serve firstly, as a reference point for Siemens’ annual reporting and secondly, help to orientate internal programs

Profit

- We contribute to our customers' competitiveness with our products, solutions and services
- We partner with our customers to identify and develop sustainability related business opportunities
- We operate an efficient & resilient supply chain through supplier code of conduct, risk management, and capacity building
- We proactively engage with our stakeholders to manage project and reputational risks and identify business relevant trends
- We adhere to the highest compliance & anti-corruption standards and promote integrity via the Siemens Integrity Initiative

Planet

- We enable our customers to increase energy efficiency, save resources and reduce carbon emissions
- We develop our products, solutions and services based on a life-cycle perspective and sound eco-design standards
- We minimize the environmental impacts of our own operations by applying environmental management programs

People

- We contribute to the sustainable development of societies with our portfolio, local operations, and thought leadership
- We foster long-term relationships with societies through Corporate Citizenship projects jointly with partners
- We live a zero-harm culture and promote the health of our employees
- We live a culture of leadership based on common values, innovation mindset, people orientation and diversity

FIGURE 5-16. SIEMENS'S SUSTAINABILITY FRAMEWORK: 12 PRINCIPLES ALONG PEOPLE, PLANET AND PROFIT (SIEMENS 2016c)

Siemens has been publishing its annual sustainability report since 2000 in alignment with Global Reporting Initiative (GRI) guidelines. The company has been presenting its progress and challenges in relation to sustainability. This contribution has been confirmed by the high rankings Siemens consistently receives in various sustainability indices. The company has been included in the Dow Jones Sustainability Index (DJSI) for 17 consecutive years and continuously ranks as one of the most sustainable companies in its industry. The Carbon Disclosure Project (CDP), Corporate Knights, Clean200, MSCI World ESG Index, FTSE4Good series, Sustainalytics are numerous other ratings and rankings Siemens is included in. In recent years they have increased their score for major improvements in climate and environmental protection activities whereas human rights, human capital development, corporate citizenship and social reporting have been noted areas for improvement (Siemens 2017l).

On the program side, Siemens has introduced some interesting initiatives in recent years. COP22 was seen as the “COP of business” where private sector accepted responsibility for delivering the resultant Paris Agreement through concrete implementation. There, the transition to a low-carbon economy was perceived as inevitable and in response, Siemens announced its ambitions of becoming the first major industrial company to be carbon neutral. The company presented its plans to reduce its CO_2 emissions in half by 2020, and by 100% in 2030. The program has four levers related to as shown in Figure 5-17: energy efficiency gains, leveraging distributed energy systems, reducing emissions from fleet and purchasing green electricity (Siemens 2017j). In energy efficiency projects alone, Siemens has already invested €32 million in 11 energy efficiency projects of which three have been completed, reduced operating costs by €1 million and saved 6,000 metric tons of CO_2. Another €100 million is expected in investments over the next four years with another €20 million projected in savings (Siemens 2017c).

Business to society (B2S) was another program Siemens rolled out which emphasizes the “*for life*” element of the new brand as well as the mission “*We make real what matters*” (cf. 5.2.1). The purpose behind it was to support external dialogue with Siemens’ stakeholders and to show how the company contributes to the 17 Sustainable Development Goals (SGDs). Further, the methodology clusters the SDGs into six impact areas (Figure 5-18a-b). It can be used by Siemens’ entities to demonstrate their societal contributions and derive strategic actions with their portfolio, local operations, thought leadership and community engagement (Siemens 2017m).

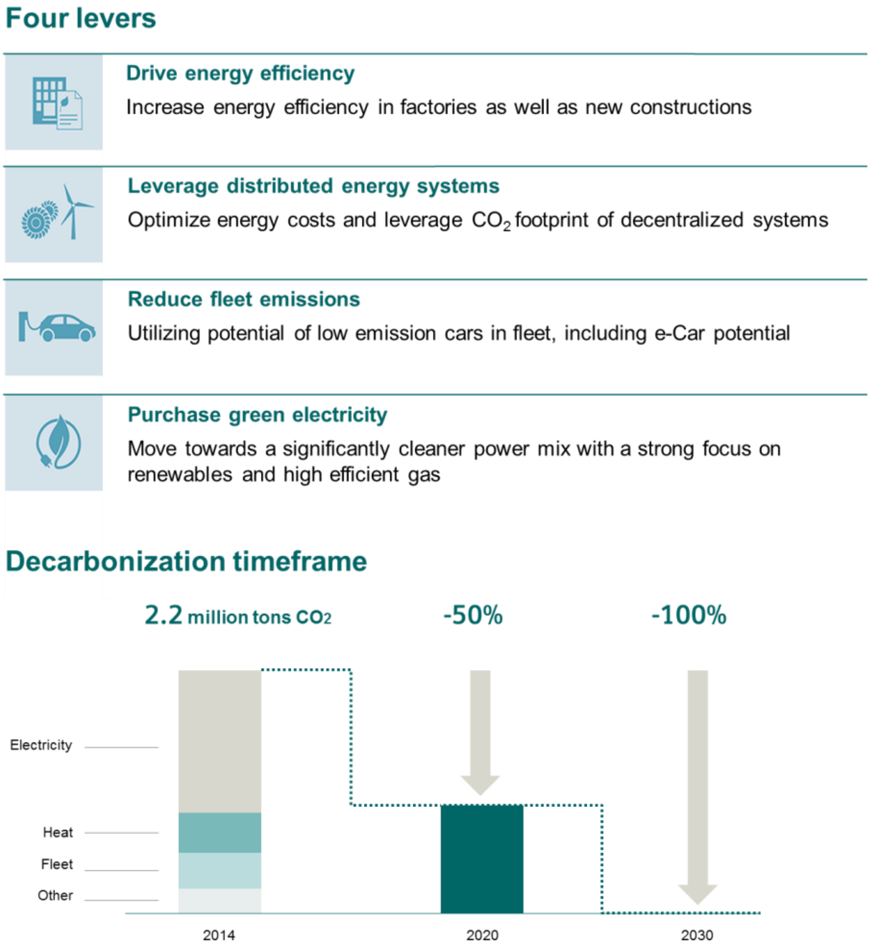

FIGURE 5-17. DECARBONIZATION AT SIEMENS USING FOUR LEVERS (SIEMENS 2017j)

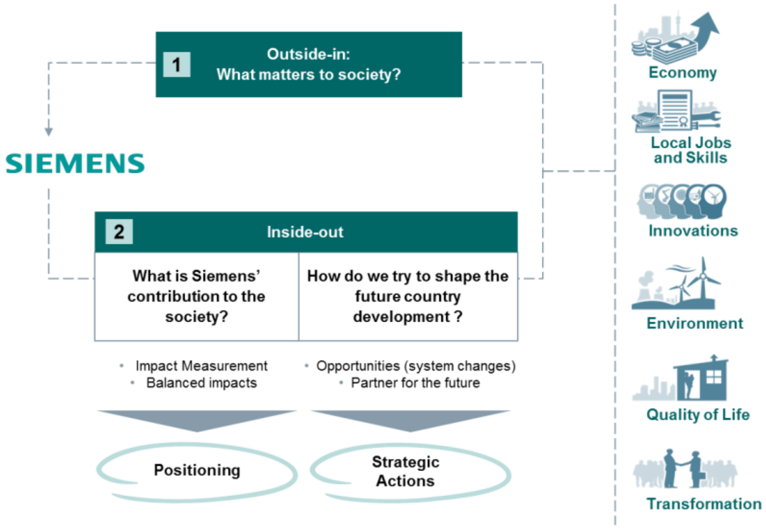

FIGURE 5-18a. SIEMENS' BUSINESS TO SOCIETY APPROACH (SIEMENS 2017m)

FIGURE 5-19. SDGS PLOTTED WITHIN SIEMENS' B2S APPROACH (SIEMENS 2017m)

To Siemens, engaging with stakeholders has many benefits for both parties. It can help to identify upcoming trends and market developments as well as new strategic opportunities through co-creativity. It can also create trust and a more positive environment to exchange knowledge and conduct business. Further, it can help to enhance Siemens' reputation as a responsible company. An overview of Siemens' stakeholders and ways in which the company engages with its stakeholders are illustrated in Figure 5-19.

FIGURE 5-19. SIEMENS' STAKEHOLDERS AND STAKEHOLDER ENGAGEMENT PROCESS (SIEMENS 2017i)

SIEMENS WIND POWER

The wind power Division's stakeholders are not much different from Siemens'. Three chapters address the stakeholder theme in from the perspective of SWP: Chapter 6 looks at the internal stakeholders and their involvement in the PDP process, Chapter 9 takes point of departure in SWP's customer's environmental needs and requirements and Chapter 10 addresses SWP's involvement in an environmental network for the management of composite waste from wind turbine blades.

The overall EHS responsibility lies with the management, particularly the chief executive officer (CEO) but they have appointed an EHS Officer who establishes the EHS specialist organization. SWP's EHS organization is distributed across the market units (cf. Figure 5-8). These experts support the management in fulfilling EHS related tasks. As previous described (cf. 2.1.2) this project was placed in the global EHS function of Global Blades at the onset of the PhD but transferred to the Division EHS function in 2014 which broadened the scope to a large degree. Division's scope includes: Setting minimum standards for EHS include strategy and targets companywide in addition to the coordination around various procedures, programs, action plans and reporting; Brokering between Siemens AG's corporate functions and other functions in SWP.

Like other MNCs, SWP employs an integrated management system which includes the latest versions of ISO 14001, OHSAS 18001 and ISO 9001. In response to certification requirements, the company has developed and communicated a combined quality and EHS policy. The policy has been revised twice since the onset of the PhD project and is currently divided into six thematic areas that reflect ISO 14001:2015 requirements (Figure 5-20): 1) leadership, 2) compliance, 3) risk management, 4) engagement, 5) product stewardship and 6) operational excellence. Within these headlines, the policy addresses compliance, a life cycle approach, transparent communication, cooperation and accountable leadership, awareness and capacity building and a preventative approach based on continuous improvements. Formerly, the EHS strategy, targets and activities of SWP were organized around the four Siemens' EHS programs prescribed by Corporate EHS (cf. Figure 5-14), the most recent EHS strategy also follows the policy headlines.

FIGURE 5-20. THE NEW COMPANYWIDE EHS STRATEGIC TOPICS AT SIEMENS WIND POWER AS OF 2016

An action plan registry was established to track all proposed, ongoing or completed EHS improvements. The registry also tracks the sum of cost savings. Based on 2016 and 2017 the registry consists of 331 companywide actions that are categorized according to the six policy and strategic topics: 34 leadership, 38 compliance assurance, 36 risk management, 45 engagement, 17 product stewardship and 161 operational excellence. For global energy and waste savings there were a total of 55 and 57 actions respectively registered.

In relation to product related environmental protection, the ecodesign activities are discussed in great detail in Chapters 6-10. The LCA methodology is well established in the wind industry (cf. 5.1.3) and also played a significant role during the duration of this project. LCAs were conducted to gather a baseline and develop our first EPDs in relation to the company's product portfolio (Siemens Wind Power 2015) and smaller analyses were done as shown in Table 2-9. Further, we participated in two projects that were run by Corporate EHS in 2012 and 2016. The first was to pilot the Eco-Care-Matrix methodology (Saling et al. 2002; Siemens 2010b). Utilizing a combination of LCA and life cycle costing methods, the goal was to compare both the environmental impacts and cost effectiveness of a rotor blade revision with its predecessor. Outcomes can be found in Appendix A which is in the form of a conference paper.

The second Corporate LCA project investigated the business case around the use of LCA for internal optimizations but only internal publications were made on the outcomes. Frankl & Rubik (2000) write about the use of LCA within business decision making processes. They conclude that the highest value of LCA is for learning. This is particularly true when companies expand their use of LCAs for solely external marketing purposes and use it additionally for internal decision making. This was also a result of the latter project.

5.2.4. SYNTHESIS

Despite Siemens 160 year history in comparison to the Wind Power Division's nearly 40 years, both companies are in constant change and frequently redefining their organizations based on market trends and customer demands. However, it can be seen that Siemens is in a more stable and advantageous position. The new "Ingenuity for Life" brand (cf. 5.2.1) and the B2S program (cf. 5.2.3) exemplifies Siemens' growing understanding of its diverse set of stakeholders and how engagement extends beyond the typical customer. SWP is seen to be "keeping up" with rapid and incessant developments due to a maturing wind industry (cf. 5.1). The brand or B2S program were never adopted by SWP despite being highly relevant. Firstly, the wind power business is "ingenious" as a new and rapidly expanding industry with many state-of-the-art technologies and services (cf. 5.2.2). Secondly, the "for life" underlines SWP's role in society and conviction to combat climate change and resource scarcity by delivering renewable energy. However, SWP's

SCoE concept ties closely into both the “Ingenuity for Life” claim and the B2S program and could be further emphasized when engaging with stakeholders.

Siemens claims to embrace the technological shifts needed to address megatrends such as climate change and resource scarcity through their portfolio of products and services. The SWP’s entire portfolio is based around the development of wind turbines and the deployment of renewable energy. They are a significant contributor to Siemens Environmental Portfolio. However, there is also an ambiguity: should environmental practices be developed in relation to product development practices or should product development practices be developed in relation to environmental practices (cf. 5.2.2). Recently, SWP has been intensely focused on establishing a robust stage gate model to manage all the technological developments internally. The product development and environmental practices described position both organizations as well structured, preventative and life cycle oriented. The need for processes, procedures and instructions still remains in order to outline the minimum requirements and indicate responsible functions. Without these, there would be a lack of standardization and difficulties measuring and monitoring progress. The policy, strategy and action plans are not static but developed over time, which are based on lessons learned and established practices throughout the company but also influence learning and new practices.

Siemens AG has an official Chief Sustainability Officer who interacts on a regular basis with the board and is likely able to introduce new ideas to management. A similar organizational role and setup is lacking within SWP[2]. Most sustainability topics were formerly driven at the Siemens corporate level and thus are less formalized within SWP. However, SWP will need to broaden their scope to include these in lieu of many things. For example the merger in which the company now has a broader footprint; wider societal pressure for businesses to align their activities with the SDGs; the upcoming EU Directive 2014/95 for CSR reporting in Europe; the changing customer base that more than ever includes investors who are concerned with ESG topics and independent evaluation on external sustainability ratings and rankings.

[2] Note that there is an established CSR Director from the legacy Gamesa organization in the new Siemens Gamesa Renewable Energy and the predominant focus is on annual reporting.

6 STAKEHOLDERS IN PRODUCT DEVELOPMENT

This chapter contains the following article:

SUSTAINABLE INNOVATION IN THE DESIGN OF WIND TURBINES: CHALLENGES FROM A STAKEHOLDER AND LIFE CYCLE PERSPECTIVE

Kristen Skelton[1], Alexandra Bonou[2], Arne Remmen[1]

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Draft manuscript

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CONCLUSIONS: PART 2

The second part of this research had a contextual aim to explore the formal procedures and social practices in relation to environment and product development at the onset of the study. The sub-questions were:

> *How are the company's environmental and product development practices characterized?*
>
> *What is the emphasis on formal procedures compared to social practices?*

Key findings as they relate to the sub-questions:

- SWP is mostly concerned with innovations at the technological level rather than system level (cf. Figure 3-8). Market, financial and technical requirements dominate discussions.
- Although environmental practices are deemed relevant by employees and have gained importance in the company since the beginning of this project, "green" product and renewable source claims are often underplayed.
- Environmental practices are highly synchronous with existing design practices and sustainable innovations are constantly emerging but from different intentions than improving the environment or increasing social value. This is exemplified by product innovations with the objective to reduce LCoE.
- Life cycle thinking is to some degree already engrained in the organization since it manufactures, installs and services wind turbines. This is encouraging but stronger linkages to environment should be made with product development practices and processes.
- The social pillar of sustainability is underdeveloped in SWP, with the exception of safety. More focus could be given to CSR topics and ESG metrics to evaluate the firm's performance.
- Employee involvement is not fully integrated in the product development process. It has been improving in recent years but employees want more frequent and earlier involvement in the process.
- The same is true for customer and supplier involvement. Customer involvement was minimal in the early years of this project, and to some degree loathed by project managers but this perception is changing out of necessity. Involvement of material suppliers and contractors downstream has also become more proactive in recent years. Authorities and certification bodies are the most involved external group of stakeholders.

Business relevance:

- There is potential for improvement in terms of shifting mind-sets on the company's fundamental purpose (social value) and the involvement of particularly external stakeholders.
- Sales and strategy functions are potential stakeholders that could help to leverage environmental practices in the Technology functions which is based on their increasing interests in sustainability over the duration of the PhD project.

PART 3

ECODESIGN SOLUTIONS

7 ECODESIGN PROCEDURES

This chapter contains the following article:

ECODESIGN PROCEDURE FOR DEVELOPING WIND TURBINES

Alexandra Bonou[1], Kristen Skelton[2], Stig I. Olsen[1]

[1] Department of Management Engineering, Division of Quantitative Sustainability Assessment, Technical University of Denmark, 2800 Lyngby, Denmark

[2] Department of Development and Planning, Aalborg University, 9000 Aalborg, Denmark

Published in *Journal of Cleaner Production, 126, 643-653*

**omitted in online version, consult above publication*

The original and revised versions of the ecodesign procedure, checklist and target setting guide can be found in Appendix B as these were not included in the publication.

8 BROKERS AND BOUNDARY OBJECTS

This chapter contains the following article:

UNDERSTANDING ECODESIGN THROUGH A COMMUNITIES OF PRACTICE PERSPECTIVE

Kristen Skelton[1], Rikke D.Huulgaard[1], Kirsten Schmidt[2]

[1] Department of Development and Planning, Aalborg University, 9000 Aalborg, Denmark

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Published in *International Journal of Environmental Technology & Management, 19(1), 40-58*

**omitted in online version, consult above publication*

10 BLADE RECYCLING: EXPERIENCES, CHALLENGES AND POSSIBILITIES

This chapter contains the following article:

WIND TURBINE BLADE RECYCLING: EXPERIENCES, CHALLENGES AND POSSIBILITIES IN A CIRCULAR ECONOMY

Jonas P. Jensen[1], Kristen Skelton[1]

[1] Department of Development and Planning, Aalborg University, 9000 Aalborg, Denmark

Published in *Resources, Conservation and Recycling*

This article was based on a paper I wrote for WindEurope, which can be found at the following link, in combination with the outcomes of the GenVind project that Jensen was a part of.

Wind turbine blade recycling: Experiences, challenges and possibilities in a circular economy

Jonas P. Jensen[1], Kristen Skelton[1]

[1] Department of Development and Planning, Aalborg University, 9000 Aalborg, Denmark

ABSTRACT

The wind power industry is a fast growing, global consumer of glass fibre-reinforced plastics (GFRP) composites, which correlates with the industry's rapid growth in recent years. Considering current and future developments, GFRP waste amounts from the wind industry are expected to increase. Therefore, a sustainable process is needed for dealing with wind turbines at the end of their service life in order to maximize the environmental benefits of wind power. Most components of a wind turbine such as the foundation, tower, gear box and generator are already recyclable and treated accordingly. Nevertheless, wind turbine blades represent a challenge due to the type of materials used and their complex composition. There are a number of ways to treat GFRP waste, depending on the intended application. The best available waste treatment technologies in Europe are outlined in this paper. However, there is a lack of practical experiences in applying secondary materials in new products. A Danish innovation consortium was addressing this waste with a predominant focus on the blades from the wind power industry. The outcomes from the consortium and the various tested tools are presented in this paper as well as the secondary applications that were proposed. The outcomes are structured using Ellen MacArthur's circular economy diagram. The "adjusted" diagram illustrates the potentials for a continuous flow of composite materials through the value circle, where secondary applications were developed in respect to "reuse", "resize and reshape", "recycle", "recover" and 'conversion'. This included applications for architectural purposes, consumer goods, and industrial filler material. By presenting the outcomes of the consortium, new insights are provided into potential forms of reuse of composites and the practical challenges that need to be addressed.

KEYWORDS

Wind Turbine Blades; Composite Material; Recycling; Circular Economy; Responsibility; Partnership

10.1. INTRODUCTION

The total wind power capacity installed at the end of 2016 was 153.7 GW which was enough to cover 10.4% of the EU's total electricity consumption in a normal wind year (EWEA 2016). With a cumulative capacity of 153.7 GW and a project lifetime of 20 years, the total number of wind turbines installed in Europe is around 77,000 (assuming an average wind turbine capacity of 2 MW).

The EU's binding target for increasing the renewable energy share to 27% by 2030, and its commitments to cutting greenhouse gas emissions by 80-95% as of 2050, emphasizes wind power's important role in the future energy mix.

However, a growing amount of wind turbines will be decommissioned, considering that:

- The standard lifetime of a wind turbine is 20-25 years.
- There are increasing repowering opportunities, i.e. replacing old components/models with newer and more efficient components/models.

A sustainable process for dealing with wind turbines at the end of their service life is needed in order to maximize the environmental benefits of wind power from a life cycle perspective. Most components of a wind turbine such as foundation, tower, components of the gear box and generator are already recyclable and treated accordingly. Nevertheless, wind turbine blades represent a challenge due to the materials used and their complex composition.

10.1.1. OBJECTIVES AND PAPER STRUCTURE

The aim of this paper is to explain the state of the art in how industry is addressing the challenges associated with composite waste and the ways in which composite waste from wind turbines can be managed according to best available technologies. We begin by providing a review of composites use in the wind industry, including material composition of the blades and current and future market forecasts. We then discuss the challenges related to composites recycling and outline the current waste treatment methods.

Next, the outcomes are described of the Danish innovation consortium, GenVind that was operative between 2012-2016. Outcomes include an overview of the different methods used for sectioning and recycling wind turbine blades as well as the secondary applications that were proposed. The outcomes are structured using Ellen MacArthur's circular economy system diagram that illustrates the potentials for a continuous flow of composite materials through the value circle, where secondary applications were developed in respect to "reuse", "resize and reshape", "recycle", "recover". We conclude by presenting other ongoing consortiums in the industry related to composites, hereunder a shift in the wind industry from "producer responsibility" to "industry responsibility" by means of partnerships and sustainability clusters.

10.1.2. A NOTE ON METHODOLOGY

The information presented in this paper is based on our experiences working in the industry (three and six years, respectively), our participation in the GenVind innovation consortium, and other similar networks and research projects in association to both of our Industrial PhDs. Important sources have been obtained from researchers, the original equipment manufacturers (OEMs), operators and maintainers (O&Ms), waste handlers and those that use the recyclates from blade waste. Recent, peer reviewed literature supplements the information contained herein.

10.2. COMPOSITES IN THE WIND INDUSTRY

Composite materials are used in a range of industries including the wind industry. The industry experiences growth rates in the use of GFRP composites (Stewart 2012), which correlates with the industry's rapid growth in recent years. In this section the structure and material composition of wind turbine blades is explained. Following, a description of the current material markets for glass and carbon fibres is provided, as well as the market forecasts for composite use in blades and decommissioning projections.

10.2.1. BLADE STRUCTURE AND MATERIAL COMPOSITION

Wind turbine blades are considered a composite structure, consisting of various materials with different properties. Although material compositions vary between blade types and blade manufacturers, blades are generally composed of the following (see Figure 10-1):

- Reinforcement fibres e.g. glass, carbon, aramid or basalt.
- Polymer matrix e.g. thermosets such as epoxies, polyesters, vinyl esters, polyurethane (PUR), or thermoplastics.
- Sandwich core e.g. balsa wood or foams e.g. polyethylene terephthalate (PET).
- Coatings e.g. polyethylene (PE), PUR.
- Metals e.g. copper wiring, steel bolts.

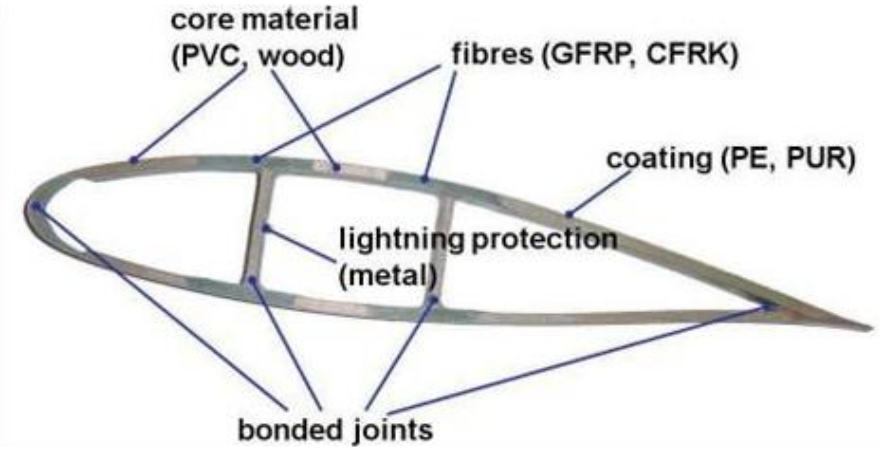

FIGURE 10-1. CROSS SECTION OF A ROTOR BLADE AND MATERIAL COMPOSITION (EWEA 2012)

The combination of fibres and polymers, also known as glass fibre reinforced polymer (GFRP) composites, represents the majority of the blades material composition (60-70% reinforcing fibres and 30-40% resin by weight). GFRP composites are advantageous due to:

- Combine properties of high tensile strength with low density (high strength-to-weight ratio) to withstand the mechanical load requirements and to optimally perform aerodynamically.
- Provide resistance to fatigue, corrosion, electrical and thermal conductivity important for the long product lifetime.
- Enable cost effective manufacturing of longer and lighter blade structures.
- Can be easily affixed with add-on components (lightning protectors, leading edge protection, and heating systems) to improve performance.

When thermoset GFRP composites are cured however, the polymers become cross-linked and undergo an irreversible process that makes recycling difficult.

10.2.2. MATERIAL USAGE PER BLADE TYPE

The average values for blade mass per unit rated power (t/MW) are shown in Figure 10-2 and based on aggregated data from fourteen OEMs (Lui 2017). The figure shows a slightly increasing ratio until turbine models above five MW. Mass reductions are seen in the larger blade types for a number of reasons, spanning more efficient designs, lower safety factors, lighter materials and improved manufacturing techniques (Lui 2017).

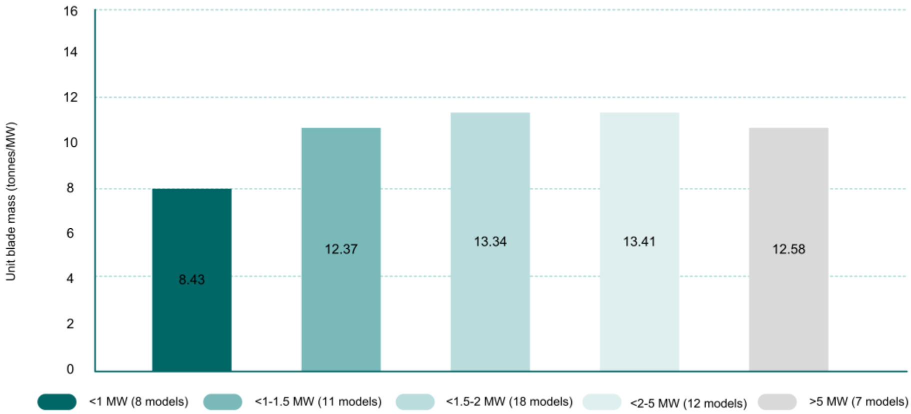

FIGURE 10-2. BLADE MASS PER UNIT RATIO POWER FOR DIFFERENT TURBINE SIZES (EWEA 2012)

Waste from the blades at the end of their life contributes to the largest fraction of composite waste. However, composite waste also arises in the manufacturing processes such as dry fibre cut-offs, cured composites cut-offs from blade edges and root ends as well as grinding dust from the finishing process. Test blades, accidental damages enroute to site and defects after installation are other minor sources of blade waste. Waste values vary based on manufacturing process and turbine models. Figure 10-3 provides an overview of other blade waste sources from a life cycle perspective (Lui 2017).

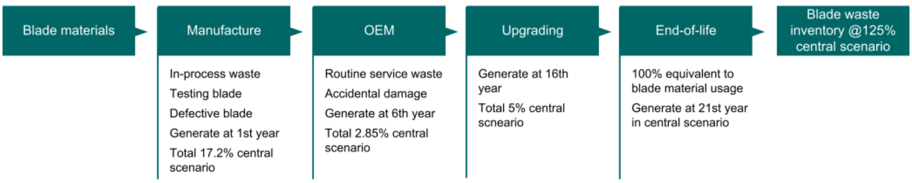

FIGURE 10-3. COMPOSITE WASTE FROM A LIFE CYCLE PERSPECTIVE (EWEA 2012)

MATERIAL MARKETS FOR GLASS AND CARBON FIBERS

Glass fibre represents the primary material in wind turbine blades. According to a market report by the German associations AVK and CCeV (AVK & CCeV 2015), Europe's production volumes in GFRP steadily grew by 2.5% in 2015, reaching 1,069 million tonnes. This correlates to 25% of the world's total production volumes and represents the highest level in eight years. Further, 34% of Europe's production (363 million tonnes) is associated with the construction sector, in which the wind power industry is included.

Carbon fibre is also used in wind turbine blades, but to a lesser degree. Carbon fibber's superior strength and higher stiffness offers many advantages over glass fibre but its higher cost per volume is a key barrier to further deployment in the wind power industry. In the same market report, the global carbon fibre demand in 2014 was 53,000 tonnes, which represents a growth of 14% over the previous year in the construction sector. The wind power industry specifically represented 14% of that demand (7,400 tonnes).

MARKET FORECASTS FOR COMPOSITE USE IN BLADES

Considering current and future developments in wind power, GFRP composite waste amounts from the industry are expected to increase (Stewart 2012). Assuming that the amount of composite material used in wind turbines is between 12-15 tonnes per MW the projected annual use of GFRP composites is shown in Figure 10-4.

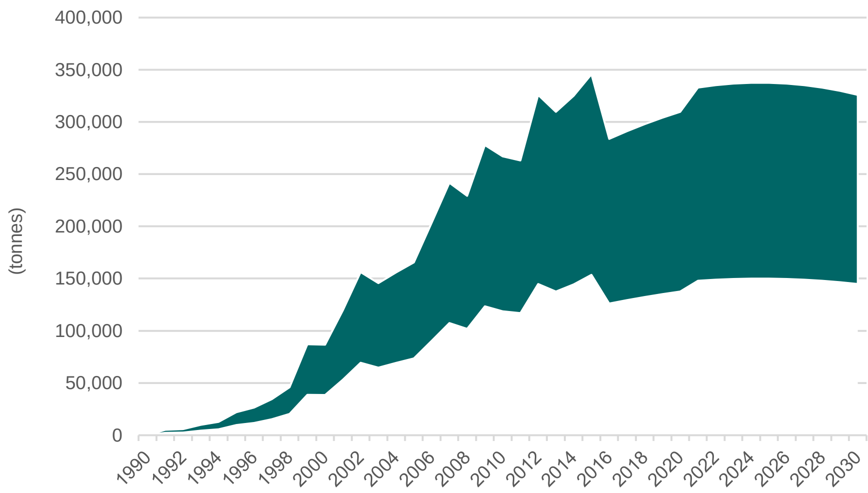

FIGURE 10-4. ANNUAL USE OF GFRP COMPOSITES IN ROTOR BLADES (WINDEUROPE 2015)

Based on the installed capacity in 2000, the use of GFRP composites for wind turbine blades was around 50,000 tonnes. The annual wind power capacity installed in Europe in 2016 attained 12.5 GW (WindEurope 2015), bringing the use of GFRP composites in blades to 150.000 - 186.000 tonnes[4], a threefold increase compared to the 2000 figures.

10.3. COMPOSITE RECYCLING CHALLENGES

Recycling of composite material is not as straight forward as steel due to the composite construction (Larsen 2009). The challenges of today do only include blades of 15-20 meters of length (Brøndsted et al. 2005), whereas the future will include the blades with lengths of 75-80 meters (Cherrington et al. 2012). Perry et al (2012) suggests that three parameters to consider: 1) Having the recycling technology available, 2) finding a dismantling solution and an access to a market for the recyclate and 3) material identification and selection for recycling (Perry et al. 2012).

Three main routes have been identified for handling end-of-life composite materials; landfill, incineration or recycling to which recycling has a number of possible routes e.g. mechanical, pyrolysis or chemical recycling (Pickering 2006). Landfill is highlighted as the least preferred option according to the waste hierarchy and landfilling of blades in Germany has been banned. The most common route is incineration. A downside is that up to 60% is left behind as ash after incineration, which will either be landfilled or used in building materials. This might be affected by local factors such as legislation prohibiting the use of waste as filler material. Recycling is the alternative option. Several research projects have looked or are currently looking into recycling of wind turbine blades e.g. ReACT, GenVind as well as the company ReFiber, who has developed a process for recycling blades. Today, a few established methods for recycling the blades are available (Larsen 2009).

Common to all of the processes is lack of a business case. The cost of recycling operations and the lack of a market for the recirculated material has been identified as the two main barriers towards actual recycling (Cherrington et al. 2012).

The energy required to produce 1kg of composite material is estimated to 111.88MJ/kg including fibre production, fabric production, resin production and the pultrusion process as well as additives in the material (Song et al. 2009).

10.3.1. FUTURE TRENDS IN BLADE MATERIALS

Blade material challenges are related to stiffness optimization, fatigue life, damage prediction methods and the production of light weight blade structures. Further, materials selection is determined by design changes, geographical locations with more hostile environmental conditions and the demand for longer wind turbine blades. Active areas in materials research include (Böger et al. 2010; Koziol et al. 2007):

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[4] The estimated usage of composites is calculated as the production of the EU annual wind capacity installed -12.5 GW, times the amount of composite material used in wind turbines per MW- 12-15 t/MW.

- Optimising the formation of chemical bonds via the curing process.
- Incorporating automatized manufacturing processes to ensure consistent material qualities.
- Introducing nano-components as strengthening agents in the fibre-matrix.
- Investigating fibre architectures - combining high performance glass fibres, carbon fibres and nano-engineered fibres to make hybrid reinforcements.
- Investigating durable coating materials to ensure erosion-resistance e.g. gel-coats, paint systems and tapes.
- Promoting cost effective manufacturing processes for carbon fibre, since the material has better mechanical properties and is financial more attractive to recover compared to glass fibre.
- Researching alternative materials that are recyclable e.g. thermoplastics, cellulosic fibres and bio-resins.

Material innovations will have effects on the production, maintenance and life time of the blades. Design and material selection processes should consider the overall sustainability of the materials chosen including their impacts on recyclability and recovery and alignment with future recycling methods (Conti-Ramsden & Dyer 2015). Materials research for blades is an important research area in (Tecnológico, Asociación Eólica Empresarial. Observatorio 2016) and see accounting for sustainability as a strategic issue (Gomez-Briceño et al. 2012).

Furthermore, there is a shift in focus from a “prevention of waste” to a “sustainable materials” agenda in national waste policies, which recognizes wastes as a resource. This has implications on turbine OEMs and O&Ms and propels materials systems thinking. Silva et al (2017) indicate that industry involvement in the waste debate and industry partnerships are essential to scale materials recovery via new business models (Silva et al. 2017).

10.4. GENVIND INNOVATION CONSORTIUM

The GenVind Innovation Consortium (2012-2016) was a project supported by the Danish National Agency for Research and Innovation. It sought to evaluate different recycling technologies for composite waste and demonstrate how composite “waste” can be reused in a diversity of products, components and secondary applications. Significant emphasis was put on the potential secondary applications of composite waste for such things as architectural structures, consumer goods, and industrial filler material using the circular economy principles. The project consisted of a number of partners from industry, academia and research institutions (Table 10-1).

TABLE 10-1. PROJECT PARTICIPANTS IN GENVIND INNOVATION CONSORTIUM

University and research institutes	Composite products manufacturers	Operators, Service and recycling companies	Potential reusers
DTU WIND	Siemens Wind Power	DONG Energy	Superuse Studios
Aalborg University Esbjerg	Vestas Wind Systems	Barsmarck	Novopan
Nottingham University	LM Wind Power	Averhoff	Midform
Force Technology	Fiberline	IF Nedbrydning	Contec
Danish Technological Institute	Velux	Davai	
	Tunetanken	Ålsrode smedie- og maskinfabrik	
	Comfill	Elcon	
	TUCO	H.J. Hansen	
		Stena Recycling	

The project involved research, technology development and demonstrations:

- Research: focused on the optimization of existing recovery processes, on the characterization of the recovered materials and on the implementation of a pilot scale study.
- Technology development: focused on developing and implementing the technology based on mechanical, thermal and/or chemical processes to recover resin and fibres from composite.
- Demonstrations: focused on validating the recycling solutions implemented to show examples of application for the recovered products.

Finally, the full solutions (technology + application) were screened in an environmental assessment focusing mainly on the energy consumption of the different scenarios. The working groups were structured around five topics under headlines that could be directed to a circular economy approach (Table 10-2).

TABLE 10-2. OVERVIEW OF WORKING GROUPS AND SCOPE

Working group	Scope
Reuse / Repurpose	Demonstration of how the whole blade can be reused in its current structure
Resize / Reshape	Demonstration of how standardized and custom-made parts can be made from the blade and used for secondary applications
Recycle	Demonstration of how recycled material can be used in secondary applications as aggregates
Recovery	Demonstration of how waste handling processes e.g. glycolysis or solvolysis can be used to extract fibres and resin and retaining best possible quality
Conversion	Demonstration of converting the composite material into new materials for other purposes

10.4.1. GENVIND AND THE CIRCULAR ECONOMY

The setup differs from the ‘classic’ butterfly diagram presented by the Ellen MacArthur Foundation. The main reason is that this has been adapted to this specific component, whereas the classic figure target full products. The circular economy basically aims at maintaining the products and materials in use for as long as possible at highest possible value. The purpose of the GenVind project was not to consider full product life time extension possibilities, but rather how the product or materials could re-enter the system at highest possible quality – either in forms as the product (reuse/repurpose or resize/reshape) or as recycled material (recycle, recovery and conversion). Figure 10-5 illustrates how positioning the work of the GenVind in a circular economy could look like. The initial focus was on end-of-life products, but through the project, it was found that manufacturing waste could be applied for some of the same applications.

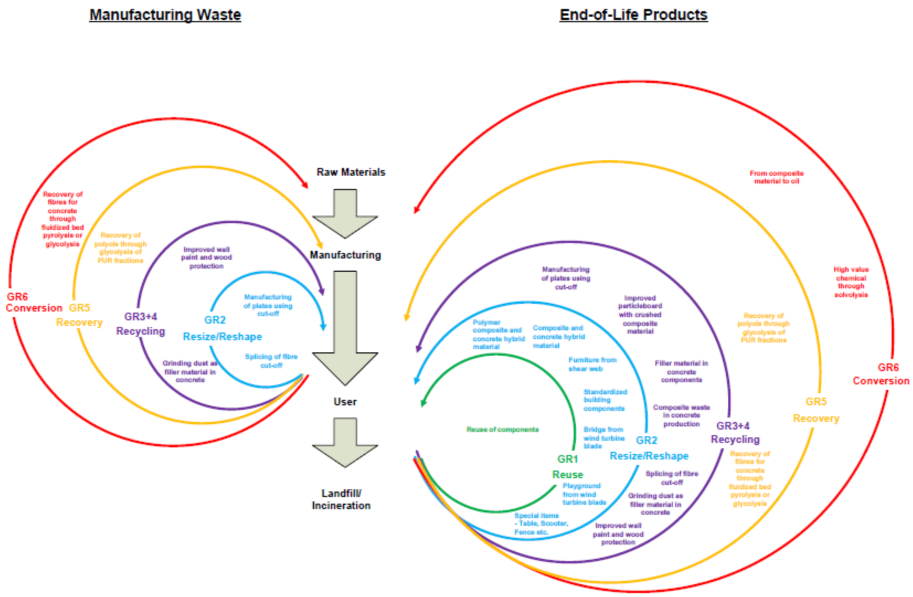

FIGURE 10-5. THEMATIC OVERVIEW OF CIRCULAR ECONOMY OF GFRP (JENSEN ET AL. 2016)

The following will give explanation to learnings regarding technologies and secondary applications tried out in the GenVind project for each of the working groups. The findings are summarized in Table 10-3.

TABLE 10-3. SUMMARY OF METHODS AND APPLICATIONS FROM THE GENVIND PROJECT

Loop	Method	Applications	Pros and cons
Reuse / redistribute	Transport	- n.a.	- Low cost, high value - Extended lifetime - Direct substitution - Difficult to assess fatigue
Resize / reshape	Mechanical e.g. wire saw and circular saw	- Bridge - Playground, urban furniture - Standardized and custom made building - Hybrid material solutions	- Little processing - High value end product - Standardization difficult - Documentation difficult
Recycle	Mechanical e.g. jaw cutter, shredders, crushers	- Filler material	- Much processing - Filler material, low value - Standardization easier - Documentation - Accumulation of waste material
Recovery	Pyrolysis Fluidised bed Solvolysis (below and above supercritical temp and pressure)	- Fibres + oil + chemical - Fibres as fillers in concrete/cement	- High processing requirements - Low value material - Properties of final material is differentiated - Accumulation of waste material
Conversion	Solvolysis	- Oil + chemical	- High processing requirements - Chemical content critical to outcome

REUSE / REPURPOSE

Reuse of a wind turbine blade was never tried out in the GenVind project. However, it is potential route of utilizing the full value of the blade. Lifetime monitoring or fatigue testing of the blade might be necessary to ensure the safety of re-using the blade (Megavind 2016). Tools for decommissioning and transporting of blades are similar to those used for installation as it is the needed reverse operation.

Reusing of in-service blades is currently taking place, and a common way to trade these is by using the e-platforms. Ensuring a blade with the right size, quality and with the desired additional lifetime can be a barrier.

RESIZE / RESHAPE

This working group focused on the sectioning of the wind turbine blades and potential secondary applications. The work in this group utilizes the product and material characteristics of the turbine blade and requires only sectioning of the blade for processing.

SECTIONING METHODS

Wire saw: The wire saw is a water-cooled steel wire with diamond particles/teeth. The wire is wrapped around the wind turbine blade and is able to cut all the different blade materials, including wood and steel. Wire cutting can section all sizes of wind turbine blades, only limited by the length of the wire, which can be extended 'infinitely'. The process is relatively environmentally friendly, regarding dust and noise emissions. The cooling water can be recycled and the cuttings can be collected. Additionally, the cuts are relatively smooth and sharp and well defined. The disadvantage is that the method is time consuming and the blade will have to be held firmly during the cutting action in order to avoid pinching of the wire.

Circular saw: Different types and sizes of diamond tipped circular saws can be used for sectioning wind turbine blades. The sizes range from handheld saws to hydraulically driven and controlled saws with blade sizes up to 2 meters in diameter. Depending on the size of the blade, the saws can section all sizes of wind turbine blades, but in most occasions it will be necessary to make several cuts in order to section the blade. This increases the amount of dust/cuttings/emissions that are produced for each section. The circular is able to make relatively fine cuts. The circular saw can be combined with different dust collecting systems, either by vacuum or water. The advantage of the circular saw is that it is possible to make independent cuts in all directions. This opens up for the possibility to extract selected materials, like the massive main laminates or balsa for special purposes from the wind turbine blade. Disadvantages are the tough working conditions and potential safety hazards for the operators.

SECONDARY APPLICATIONS

Bridge: One potential application is using the wind turbine blade as a bridge. During the project this reached the design phase and is still awaiting final installation. The bridge was targeted an area in Aalborg, Denmark, where it could substitute the construction of a ‘normal’ bridge by creating a path from a peninsula to an island (Figure 10-6).

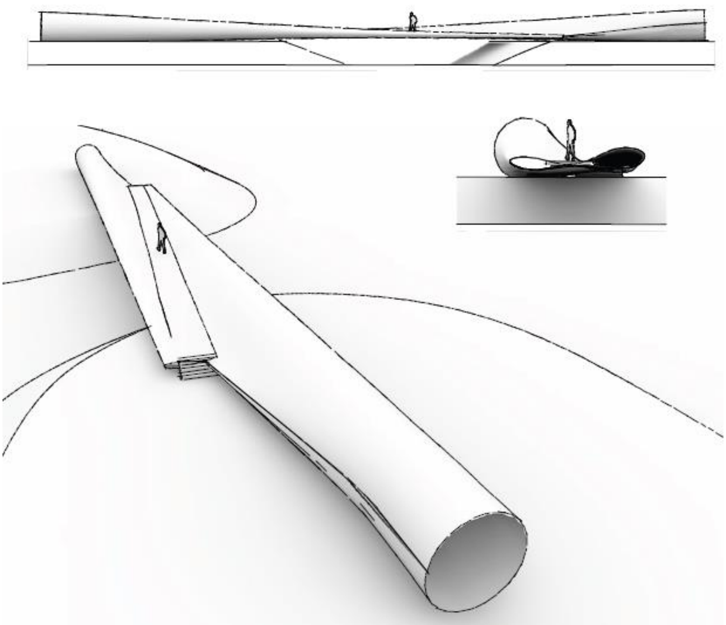

FIGURE 10-6. BRIDGE DESIGNED BY SUPERUSE STUDIOS

Several designs were suggested and considered, but ultimately using the original structure of the blade was assessed to make it most durable. However, a requirement to use it for public infrastructure is that the blade needs testing to verify the strength. This has an impact of the feasibility, and if intended going forward, specifications and standards must be considered to optimize the process.

The final design is two blades laid next to each other with the root end opposite to each other. The two open ends will then have light installed and can be used for changing rooms – making most value out of the blade.

Identified barriers to using the blade as a bridge is a) economics, although not more expensive than the alternative bridge, b) testing of the blade (who has the expertise/experience in testing old blade for bridge material), c) cutting of the blade to meet a certain design, d) transport of the blade and e) construction of the blades (foundation design etc.).

The process has shown that working 'out of the standards' requires some work and gaining experiences on this topic is crucial to overcome these barriers.

Playground and urban furniture: Using the blade as a structural element in design and architecture is another strategy tried out to extend the lifetime of the resources used. This has shown possible in four projects that are already carried out e.g. the projects:

REwind Willemsplein: Durable, indestructible seating with iconic quality. Waste streams: 9 x 6 m rotor blades, concrete rubble aggregate made from 100 % recycled concrete rubble.

Wikado: playground with added value and smaller ecological footprint built for the same price as a comparable standard playground. Waste streams: 5 x 30 m rotor blades, fighter plane cockpit, Nike grind sports floor.

Kringloop Zuid: A blade as an iconic place marking signpost. Waste steams: 1 x 30 m rotor blade, waste steel sheeting, reclaimed window frames.

REwind Almere: Durable and indestructible shelter. Waste streams: 4 x 30 m rotor blades.

The perspectives for these playgrounds have shown that implementation and several purposes and designs are possible. A study, made during the GenVind project, showed that if 5% of the Netherlands' yearly production of urban furniture was using wind turbine blades, the annually estimated wasted turbine blades would be removed from the waste steam. Price wise the level is comparable to the price ranges of urban furniture from other materials (GenVind 2016).

For issues such as flammability, the blades are not treated with flame retardants and decomposition of the plastic will normally start at 300 degrees Celsius. For water tightness, when coated, absorption of moisture is not an issue and for toxicity, the composite material does not show toxicity at normal temperatures (below 200 degrees Celsius). Therefore, the main barriers for implementation are the availability of blades to the designers at the right time as well as limitations to design freedom due to size and shape of the blade.

Components: Partial use of the entire structure to produce various items such as furniture or construction material has been tried out during the project. The strength is that the activity utilizes the characteristics of the material that is strong, light and durable. During the project it was found that several different objects can be made with relative high value through this process.

The main challenges to consider is a) transport of the structure, b) design limitations due to the original structure, c) the glass fibre content has an impact on the processing costs as a high content will require diamond-like carbon coating on the cutting equipment (more time demanding and expensive and d) that health and safety precautions may need to be taken, when processing large-scale items as well as handling micro particles of glass from dust.

Further, from a design perspective the turbine blades have concave structures and varying degrees of thickness, so producing uniform components in higher volumes is difficult and the cost-efficiency will relatively low.

Hybrid material: Several hybrid material solutions were tried out during the project. Using a re-sized piece of the blade together with another material to give new characteristics for other secondary applications was tested.

A sandwich composite made of bi-axial thin glass fibre laminate as a core material is cut out from the wind turbine blade and used to manufacture a hybrid material with a layer of concrete. The aim is to improve the performance of the concrete in compression and to make a lighter material. Possible applications for this is long tables (4 meters) with only four legs by utilizing the different

The key challenges is in process was to identify a glue to fix the two materials together as well as ensure cut-out of a thin layer from the turbine blade. To make the product even lighter, the parts of the blade including balsa wood can beneficially be cut out. It is a challenging, time-consuming process, so improvement is needed for this.

OBSERVATIONS ON RESIZE / RESHAPE

Using cut-outs of blade structures to make building components is in theory an attractive solution to extend the lifetime of the material. Processing has shown to be possible with available tools, however, it has shown during the project that the cut-out requires extreme precision and that tear and wear on the cutting tools is large due to fibre content. Use of diamond saw has proved to be the most promising tool tested, whereas water jet cutting was expensive as low cutting speed was needed.

From an environmental point of view, the theoretical idea of resizing or reshaping the blade to make use most of the blade, is good, as this keeps the materials in use for longer and potentially substitutes other materials. Also, although it requires some processing, this is mainly energy use and not exceeding the energy needed for virgin materials. However, there are still processes that need improvement to be energy and cost efficient.

RECYCLE

To recycle the blade, rough intersection of the blade is often needed. The appropriate technology depends on the purpose or use, the local environmental requirements, and the size of the blade.

RECYCLING METHODS

Jaw cutter: The jaw cutter is one tool for sectioning wind turbine blades for recycling purposes. The hydraulically driven jaw produces a rough cut through the material, and the material is more or less crushed in the cutting zone. The methods can handle large sizes and volumes, but it is difficult to control the dust and fibre emissions; it is necessary to have a water fog to control the dust; and it is necessary to sanitize the area after completion. The sectioned materials are prone to emit dust and fibres during transport, which increases the demand for proper stowing and protection for transportation.

Shredding: Shredders are rough forms of mechanical processing. Normally this process will include a series of lateral placed cutting wheels that cuts the composite between opposed cutting wheels or fixed cutting plates. The rough process will often reduce the mechanical properties of the material. However, it is a method that is usable for large amounts of material, but sorting or other post-treatment is mostly needed.

Crushing: Crushing is a relative general term that includes several kinds of rough downsizing (including shredding), but also downsizing to even smaller samples. As most composites have both high elasticity and ductility as a consequence of the fibre reinforcement, the crushing has been tested using different kind of hammer mills. To reach an acceptable level of homogeneity of the secondary material, the hammer mill process has been followed by using either ball mills or plate mills. After that a sorting using either cyclones or filters to end out with a homogenous material in terms of sizes.

SECONDARY APPLICATIONS

Particleboard with crushed GFRP: Adding crushed material to particleboard was tested. The main reason was to increase the strength of the particleboard, so the thickness could be reduced, which would have positive outcomes related to storage, transport, installation etc.

However, adding different portions of crushed material to the existing ‘recipe’ did not reveal an increase in strength of the particleboard. Different testing and analysis was done, which showed that the downsizing and homogeneity of the crushed material did not meet the expected standard. Later, this was solved by sorting the crushed material, however the material had a tendency to cluster in the particleboard and not disperse, so the hoped for increase in strength was never realized.

Improved wall paint for wood protection: Another secondary application tested in the project was using GFRP dust as an additive in wood paint. The tests showed an increase in UV stability and a protecting effect of this. The dust dispersed nicely in the 30 different paints tested and gives stable mixtures, which according to the exposure tests and mechanical tests has equal or better properties than normal additives.

Barriers to this is that the dust needs to be maximum 50 μm. This requires additional processing and sorting of the material, which is time demanding and increases the costs. Another challenge is documentation of the chemical composition as this is crucial for actual implementation in a production line.

OBSERVATIONS ON RECYCLING

One observation is that getting a homogenous mass was quite difficult, with quite a lot of processing steps. This means higher costs, energy use and time consumption and with an expected low value of the outcome material, this has implications on the potential business case.

Secondly, dispersing the material into products was a challenge too, which means new manufacturing processes for using the material as filler material, which might have consequences for the likelihood of integrating the material in the production.

Thirdly, some of the crushed material contained polyester-based GFRP, which gave a bad smell. This led to that documentation and knowledge the chemical content was necessary to even consider adding this to an existing product line. A key challenge in this respect is documentation of the materials in the waste material to control potential hazardous material.

Other aspects includes that adding the composite material to ‘clean’ products as particleboards, which is made of wood, might have implications on the recycling of these at a later stage. Mixing material streams is not in line with the theoretical aspects of circular economy, and does also show implications in this case.

Further, the glass content increases the tear and wear on the machinery built for handling other materials.

RECOVERY

In general, there are four process related to recovery (tertiary recycling) of composites meaning recycling of parts of the material – either regenerated fibres or chemicals.

RECOVERY METHODS

Pyrolysis: Thermal decomposition of GFRP is taking place by incineration of the organic polymer binder in a process, where temperature is controlled. Thermal decomposition with the target of extracting fibres, energy or pyrolysat is a complicated process, where a trade-off between removal of binders and lowest possible temperature to avoid fibre weakening. In order to be able to do so a mechanical downsizing of the material is needed before the pyrolysis process can take place.

‘Fluidised bed’: Another to thermally decompose the polymer matrix of composites is through the ‘fluidised bed’ process. In the GenVind project, this was carried out at University of Nottingham. The composite fractions will be heated to 450-550^{0}C on a layer of silica sand, which is fluidized when warmed by a flow of hot oxygen rich air. The layer can oxidize and thereby decompose the polymer matrix. Hereafter, the fibres and other filling material will be contained in the air flow, and in the end of the process the regenerated fibres can be separated using a cyclone.

Solvolysis below near or super critical temperatures and pressure: For solvolysis under these circumstances (meaning <100°C and/or <1 bar) is reactive solvents used such as nitric acid, ammonia or glycol, for chemical decomposition of the polymer matrix. The result of this chemical decomposition process is pure fibres without resin, an inorganic leftover and the organic decomposition material, which depends on the solvent (e.g. bonds made by reactions with monomers of the resin)

Solvolysis at near or super critical temperatures and pressure: When the temperature and pressure reaches a critical point the properties of the solvents changes, which can result in improved solvolysis properties and thereby better decomposition of the GFRP. At near and super critical conditions water or ethanol is the most common solvent. The choice of solvent defines the exact near and super critical temperatures and pressures. In general, ethanol has a lower critical temperature and pressure than water, which makes the ethanol increasingly interesting as a solvent. Different test has shown that thermoset resin with cross bond structures like polyester, phenol or epoxy, can be decomposed to lower chemical connections. Further, it is shown that near and super critical ethanol can make selective cleavage of specific bonds like ester and ester-amid bonds and thereby dissolve thermoset plastics.

SECONDARY APPLICATIONS

Recovered fibres in concrete: Using the recovered fibres to integrate these in concrete production was another test. The recovered fibres were mixed with micro-silica while the resin is still liquid, to make an increased adhesion between the fibres and concrete.

Barriers to this is that it requires advanced and a significant amount of processing to recover the fibres, which substitutes another low-value filling material.

OBSERVATIONS ON RECOVERY

The recovery processes are highly specialized, which first of all puts a limit to, where it is being offered and how widespread it can be. Further, the processes are demanding in terms of time heat and energy, which again has implications on feasibility of the process.

The processes are still mainly lab-scale or pilot-scale and needs to be shown in full-scale.

For secondary application, the material is often more homogenous than the recycled material, but the accumulation of ‘waste materials’ remains and issue.

CONVERSION

In the conversion process the composite is converted into valuable chemicals and materials as a ‘by-product’, and thereby adds value to the material. In the GenVind project, it was succeeded to turn GFRP into an oil with high calorific value (equal to bio oil), and extract the fibres without resin left on them. The oil was remarkable in the sense that the calorific value is approximately 40MJ/kg, so the use of the oil is comparable to bio oil. The fibres are recovered without significant leftovers of the resin and have tensile strength in the range of 80-90% of virgin fibres.

The tests are still at lab scale, using a reactor of 280mL with temperatures of 200 – 325 °C and pressure up to 300 bar. The result showed that the temperature needed to be at least 300 °C to dissolve the resin, whereas the pressure could drop below 100 bar without significant consequences of quantity and quality of the oil. The project still awaits pilot testing.

Barriers to the project are that the GFRP needs to be cut into smaller pieces as well as it is a demanding process in terms of requirements to tools, energy and chemical consumption.

From an environmental point of view, the process offers an alternative to landfill or incineration. The extracted oil has a five-fold calorific value of GFRP, the water used in the process can be used in a closed-loop system and the fibres can be recovered for new purposes.

10.4.2. DISCUSSION BASED ON GENVIND FINDINGS

The experiences from the GenVind project are an addition to the existing knowledge regarding GFRP recycling. Secondary application of (some) of the composite is possible, even adding value to the ‘waste’ product is a possibility.

For processing of the material, the low bulk density of the material possesses a challenge in terms of keeping transport costs down. This often means an on-site downsizing or cutting in order not to ‘transport air’. Downsizing and cutting is associated with a range of environmental and health related aspects that need to be addressed e.g. dust emission. Mechanical processing is possible, but the tools are exposed to wear and tear (mainly because of the glass), and it is relatively difficult to get a homogenous material stream. Post-processing is technically difficult, mainly available in lab-scale, and pyrolysis requires a post-processing of the fibres (and still with low quality), whereas solvolysis is better at extracting the fibres, but deals with chemical and energy dense processes.

A qualitative assessment of the secondary applications in the GenVind project shows that the higher value is related to the ‘inner’ circles of the circular economy diagram, and the least processing costs. Secondary applications that makes use of the composite materials properties has a higher value (reuse/repurpose/reshape), by benefitting from that strength and properties is maintained and price and environmental impact kept on a minimum.

However, the secondary applications require the most information about the condition of the material used and the most advanced design requirements, in terms of utilizing the properties and shapes of the GFRP. Different sizes and shapes makes it difficult to make standardized processes, which increases the processing demands

Further, when assessing the ‘business model’ of GFRP in a circular economy, some learning on barriers need to be overcome, which asks for further research into the field.

First of all, there are still ranges of recycling technologies that can be considered for this purpose. However, as shown by the secondary applications, the optimal recycling process really depends on the secondary application. This means that it is necessary to minimize the processing in order to keep the cost down – in short, a fit to purpose strategy.

Recycling in terms of retrieving the original materials with original properties is not possible today. The project has shown good progress in extracting the fibres with properties close to virgin materials, whereas the resin is for the main part only usable for energy recovery. An additional comment is that this has only been succeeded in lab scale tests and the energy consumption and costs to do so, does not match the price of the virgin materials.

Some parts of the blade are only relevant for shredding, and it is possible to make relative high volumes with uniform secondary material. This is positive in some applications, or as a substitute for filler material. As shown there are challenges in integrating these into products, and relatively many processing steps, which means high price and environmental impact. Further, there is an issue regarding documentation of the content, which is not widely available and accumulating waste materials as filler in products is not in line with principles of circular economy.

Taking a broader look at the market for GFRP recycling, there are still barriers to overcome. As the processing price will be relative high compared to virgin fibres, economies of scale is essential. However, even with today's volume, economies of scale are still a problem. The GFRP are placed worldwide (with regional clusters though), and there is a variety in size, composition, and market conditions for recycling, which affects the recycling. A stable stream of consistent material is needed to integrate the secondary material into the production. Further, the level of recycling maturity in the different regions, where the GFRP are placed differs significantly, and to make the business model work, transport over long distances is not feasible, so a decentralized approach is preferable.

Another issue related to this topic is documentation, when waste becomes a resource. This is a challenge when integrating GFRP into new products. Often the chemistry is interesting or the expected condition of the product, which possesses challenges. How to document this after 20 years needs to be addressed if the material should be used for more than filling material. Further, the project has shown that impurities can occur e.g. metals, fillers, other plastic types, which is also not preferred for integration into new productions.

The GenVind project has highlighted status, barriers and potentials, but does also acknowledge that there is still room for improvement and suggests that the topic could be elevated to making an international research project, where best practices can be developed and experiences can be shared. This calls for collaboration between research and industry to advance the circular economy of GFR.

10.4.3. FROM PRODUCER TO INDUSTRY RESPONSIBILITY

Extended producer responsibility (EPR) is defined as "an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle" (OECD 2001). EPR as noted by Lindhqvist

(2000), is the implementation of policy instruments to promote cleaner production and this has been suggested as a viable policy intervention for the wind power industry (Ramirez-Tejeda et al. 2017). EPR can be extended not just to the downstream phases but also to the upstream phases of a product's life cycle including the choice of materials. The term "extended" denotes an enlarged, or widened, scope. In this sense, an OEM of wind turbines can either independently or in collaboration with customers, waste handlers and other actors downstream work to improve the conditions for its product in a circular economy. This includes all the 'loops' presented in Figure 10-5, by advancing the product design, regulation, recycling technologies or conditions for a secondary market for the 'after-life', while also collaborating in parallel with suppliers upstream to make the composites more sustainable or find composite alternatives (Figure 10-7). This additional involvement of value chain actors shifts the responsibility from just the producer to that of the industry as such. As found by Jensen & Remmen (2016) a similar strategy has been ongoing in other industries e.g. automotive, shipping and aviation, where enhancing of circular economy needs partnerships and data exchange along the value chain.

Based on recent theoretical perspectives on sustainability transitions (Gaziulusoy & Brezet 2015), partnerships have become a key enabler for companies to realize more sustainable solutions (Gray & Stites 2013; Saling 2015; UN 2017) - especially those using a quadruple helix approach (European Union 2016). In the wind industry, there is an amenity towards industry collaboration for addressing composite waste from blades, amongst numerous other topics (Sovacool & Enevoldsen 2015). A list of European, industry driven R&D projects addressing possible technological innovations both upstream and downstream the value chain are provided in Table 10-4. They are founded on mutual objectives to implement sustainable principles in their operations, throughout their value chain and improve the environmental profile of their products.

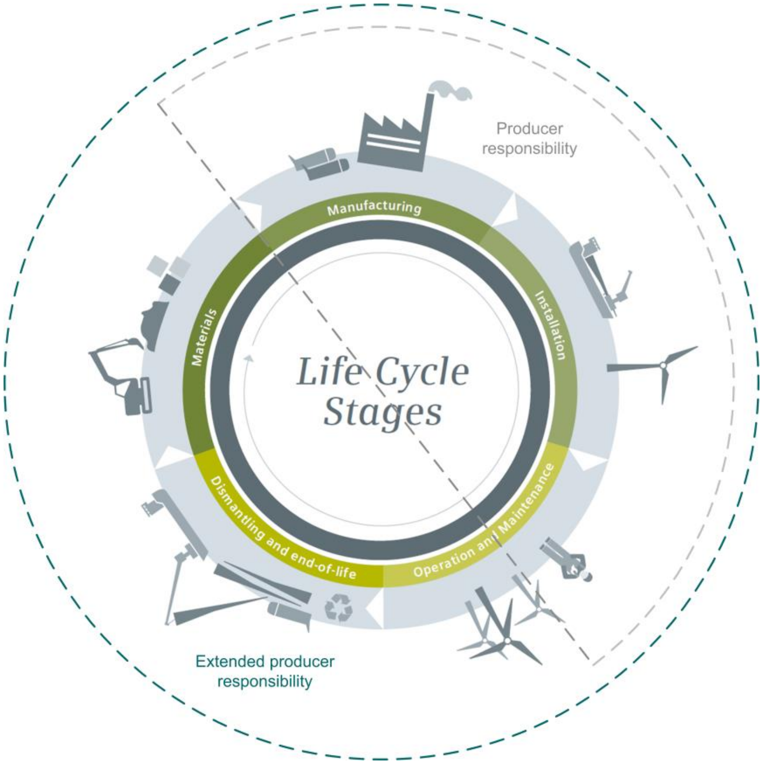

FIGURE 10-7. EXTENDED PRODUCER RESPONSIBILITY IN THE WIND INDUSTRY

TABLE 10-4. CHRONOLOGICAL LIST OF EUROPEAN INDUSTRY DRIVEN AND GOVERNMENT FUNDED R&D PROJECTS FOR COMPOSITE WASTE (NON-EXHAUSTIVE)

Projects	Source
FiberEUse Large scale demonstration of new circular economy value-chains based on the reuse of end-of-life fibre reinforced composites. *Date: 2017-2021*	Link
Dreamwind Investigating new ways to recycle and manufacture reusable composite materials for wind turbine blades via bio-based resources and stimuli-responsive materials *Date: 2016-2020*	Link
LIFE BRIO Project Optimising procedures for the dismantling of wind farms, taking into account the proper management of composite waste from blades, as well as developing policy and legislative recommendations to the European Commission *Date: 2014-2017*	Link
GenVind Innovation Consortium Demonstrated how composite waste can be applied in different products, components and structures which were based on cradle-to-cradle philosophies *Date: 2012-2016*	Link
Recycling of Waste Glass Fibre Reinforced Plastic with Microwave Pyrolysis Recycling FRP thermosets via microwave pyrolysis *Date: 2011-2012*	Link
EURECOMP (Recycling Thermoset Composites of the SST) Recycling FRP thermosets via solvolysis *Date: 2010-2012*	Link
REACT (Re-use of Glass Fibre Reinforced Plastics by Selective Shredding and Re-activating the Recyclate) Recycling FRP thermosets via mechanical processes *Date: 2003-2005*	Link

10.5. CONCLUSION

The paper has described the expected development in use of GFRP in the wind industry and the associated challenges in a circular economy perspective. However, findings from the GenVind project shows that adopting circular economy to address the challenge, the blades and composite material can be used for various applications, where the end-of-life blade adds value. Further, the project also showed that in terms of optimal solutions, there is no one-size fits all. The project shed light on some potential new technologies for recycling of composite material, where the valuable part of the output is high calorific content oil and fibres with relative high tensile strength. As shown, a range of projects within the EU has investigated this topic and there is still room for improvement. However, bridging the learnings from the country and company specific strategies to an industrial strategy seems like a promising solution to further advance the topic through partnerships and collaborative efforts. However, the individual producer still does have a potential and responsibility to support and advance the development of end-of-life solutions to its product.

CONCLUSIONS: PART 3

The third part of this research had a practical aim to develop, integrate, evaluate and refine ecodesign practices in accordance to the business objectives. This chapter summarizes key findings and their business relevance.

How has ecodesign evolved in relation to formal procedures and social practices?

How have the company's business objectives been met?

Key findings related to the formal procedures:

- Procedures are necessary but suitable participatory processes are more important than developing the "right" tool.
- The participatory process for developing ecodesign procedures enabled an open and responsive strategy to the various employees' inputs as seen with the five iterations over four years.
- One environmental KPI per project became the minimum standard and overall responsibility was allocated to the project manager as (s)he is the typical broker between functions.

Business relevance:

- Simplification in the beginning and gradual but continuous improvements was the method that enabled adaptive learning (cf. Figure 2-6).
- SWP is a learning organization within a maturing industry and future focus should be predominantly on community based practices rather than procedures. Workshops and communication around ongoing environmental and product development activities are effective methods and should be used more frequently.
- A combination of top-down and bottom-up strategies are needed. The project was initiated from bottom-up which helped to secure buy-in from project managers but ultimately more strategic decisions were needed earlier in the PDP, requiring a more top-down strategy in order to have a more significant influence on the designs.
- Since the product development process is continuously being revised, a lot of effort is required to remain aligned. This requires constant dialogue with those refining the process and the ecodesign procedure must be flexible and adaptive to these changes.

Key findings related to the social practices:

- SWP's stakeholder engagement falls somewhere between '*stakeholder information*' and '*stakeholder response*' and is based on uni-directional communication forms, e.g. EHS policies, EPDs, annual reports.
- Sales and customers revealed a lack of dialogue prior to, during and after the tender phase despite widening stakeholder interests for timely and transparent engagement. Partnerships are envisaged to openly and collaboratively address some of the industry's key sustainability challenges.
- SWP should adopt extended producer responsibility and help "shake" industry stakeholders into action to advance common sustainability goals and foster mutual industry benefits.

Business relevance:

- The last point is especially relevant because the customer profile is changing. The former customer landscape consisted primarily of utilities but is diversifying to include investors and "green" financiers who are more concerned with environmental, social and governance (ESG) criteria. Additionally, wind energy is expanding into non-OECD markets where governments are being funded through World Bank and IFC loans that are more stringent to ESG criteria.
- Further, the sales and tendering process is also in a transition, where the industry is moving towards auction based tenders that secure long term contracts, guarantee payment of pre-defined energy amounts produced, and consider additional factors beyond just price since they are awarded by governments.
- Stakeholders and strategies for managing them in project based organizations like SWP, who develop capital assets of industrial scale is significantly different than manufacturers and service providers of conventional mass produced products.
- SWP has a perceived advantage to other industrial manufacturers because they offer "green" products of overall value to society. However, this claim should be more integrated as part of the core philosophy and operational culture. Societal expectations are likely to increase in this regard.
- Industry and academic partnerships are essential to scale sustainable innovations and new business models as evidenced through SWP's participation in networks like GenVind and WindEurope and the various master and industrial PhD projects.

CONCLUSION

11 REFLECTIONS AND FUTURE DIRECTIONS

The six sub-questions were addressed in Parts 1, 2 and 3 so this chapter presents the overall conclusions. The main research question is addressed in section 11.1 which is followed by a reflective summary of two unexpected learnings. To conclude the thesis, suggestions for further research are provided in section 11.2.

11.1. CRITICAL REFLECTIONS

From a pragmatic tradition this industrial research explored: *How can ecodesign be cultivated in Siemens Wind Power in a way that incorporates both formal procedures and social practices?* The project was derived based on a predefined set of business objectives such as a mandatory corporate standard, increasing customer demands and a lack of environmental life cycle thinking in product design. A design-based research strategy was applied using a variety of methods over a longitudinal timeframe. Analysis was divided into three parts: a conceptual frame, a contextual frame and the ecodesign solutions that resulted.

The overall finding of this research was that an initial foundation for ecodesign practices was cultivated in SWP and the initial business objectives were met. An ecodesign procedure based on a procedure, checklist and target setting guide were iteratively developed, integrated, evaluated and refined in accordance to the corporate standard. Contributions were also made to the development and communication of a series of full-scale LCAs during the midpoint of the research project to transparently communicate product environmental impacts. The processual aspects such as when and how to conduct an LCA or publish an EPD were linked to the ecodesign procedure as a result. These outcomes represented the formal procedures for ecodesign.

However, the participatory development of the formal procedures and their use as boundary objects became more important during the process than the procedures themselves. This was evidenced during the various iterations such as when they were tested in real design projects with project managers, when feedback was gathered regarding their relevance and appropriateness during workshops and when they were used to negotiate meaning and align with other cross functions during semi-structured interviews. Engagement in practice as a methodology was valuable and the brokering role built internal capacities and supported adaptive learning around life cycle thinking. Thus ecodesign can be strengthened when the dualities of participation and reification are incorporated.

Below I reflect on two unexpected learnings which exemplify what I mean by the cultivation of social practices:

11.1.1. CHALLENGING THE NEED FOR AN ECODESIGN PROCEDURE

Formal procedures such as the ecodesign procedures and LCAs are important. As one example, the procedures helped to formalize in a normative sense, the ecodesign requirements from corporate. Setting a minimum requirement for one environmental target per project and developing a target setting guide was relatively easy to structurally align with the gates and milestones of the product development process. What came as a more interesting task was the dialogues with the product developers such as the negotiations around whose responsibility and when in the process environmental changes were possible as well as how to establish worthwhile and measurable targets. After the first year of implementation ideas emerged how to adapt the procedure and merge safety requirements with it. Today, the procedure is in the process of being expanded to apply to all scopes of projects rather than just new or revised product developments. This means environmental and safety targets will be required for new factories or factory expansions, etc.

As a second example, the LCAs and EPDs that were developed in 2014 helped the engineering and Project Management functions to better visualize what was meant by environmental impacts and created a sense of tangibility to the subject. For some project managers and engineers, the LCAs and EPDs also instilled a new perspective on environmental responsibility, where they began to question their role in decision making throughout the product development process. Today, LCAs have become a more integrated activity and more frequent requests are received from the engineering and sales functions, which is likely due to a combination of external stakeholder requests and internal awareness of their value. Based on these two examples, the use of the formal procedures helped to create dialogue and generated sense making around environmental topics. Over the project timeframe an adaptive learning process was evident. However, the adaptive learning process was not solely dependent on the formal procedures. Rather, it was through the process of capacity building and communicating around life cycle thinking and product environmental impacts as well as the practical use of the formal procedures that fostered situated learning. In this respect, the brokerage role and participatory elements were equally valuable to the reified structures.

However, an ecodesign procedure was not crucial for driving environmental improvements. Environmental improvements based on product innovations are routinely and inadvertently emerging. This is driven by the company's, and the industry's, objective to achieve levelized costs for wind energy. Further, life cycle thinking is to some degree already engrained in SWP since it manufactures, installs and services wind turbines. This is encouraging but stronger linkages to environment should be made when product innovations are planned and improvements to both products and environment should be better disseminated internally and externally. One example is improving the end-of-life support for customers. Quantitatively measuring these improvements and communicating them more in the marketing material will help to create a more complete profile of the product and affirm the importance of environmental conscious design for the various cross functions involved in the product development. Environmentally and socially oriented storytelling around these innovations can be used to praise and positively reinforce the cross functions as well as motivate more environmentally intentioned designs. If the company operated with the conviction to create social value and business-as-usual was to think safety, environment, quality and cost in all operations, then normative procedures could be reduced or avoided all together.

11.1.2. LEVERAGING STAKEHOLDERS TO CREATE SOCIAL VALUE

Originally, the expectation was to work closely with design and process engineers as commonly depicted in ecodesign literature. They were a relevant group of actors, since we knew what aspects could be improved such as the material efficiency of a component, the waste generation from a manufacturing process, the reduction in service visits, etc. Many of the engineers have personal interests related to environmental topics but sometimes their functional roles conflict with this. However, project managers were a more appropriate function due to their broader scope and involvement throughout the product development process and their boundary spanning role between cross functions. They are typically involved during the planning, execution and evaluation phases of product development where they manage project targets and documentation and converse with the management at gate reviews. This is also a finding of recent ecodesign literature (cf. 3.2.2). Further, risk management and stakeholder management are two central activities of project management that correlates well with life cycle management (Huemann & Silvius 2015).

Both engineers and project managers were to a lesser degree involved in the conceptual phases of product development. If radical or societal level changes are sought such as how SWP can contribute to wider energy transitions in relation to energy storage or to the integration of electricity in the mobility sector, then the business developers and strategists were more appropriate. They interact before the official start of the product development process as part of the product portfolio management process and they have a larger influence on developing new business models. However, there is a limited amount of research available on how sustainability is integrated in the innovation portfolio management decision making (Brook & Pagnanelli 2014). Further, the sales function gained interest in the EPDs and became a key liaison in linking the need for EPDs and other environmental marketing materials to the PDP process. Requirements in the tender phase thus have significant weight and can be used to motivate and leverage sustainable innovations internally with the help of our customers and sales functions.

Siemens is accustomed to collaborating with research institutes and authorities (cf. 2.1.1) but other external stakeholders are usually provided uni-directional information. SWP's stakeholder management process needs to be adapted because the customer base is diversifying to include other types of financers and the way in which tenders are auctioned is changing. Related to mega-construction projects such as wind farms, customers have a higher degree of influence and involvement due to the highly customized character of their projects. Further, governmental and wider public interests should be accommodated since megaprojects carry profound social responsibilities during and beyond the project installation. They have significant impact on the development of society and more capacity to change the structure of a society (Flyvbjerg 2014). SWP should thus embrace this extended producer responsibility and take the lead in “shaking” industry stakeholders into action to advance common sustainability goals. If embraced, strategic partnerships and mutual industry benefits can be fostered. However, similar to sustainable portfolio management, a systematic review on stakeholder management in megaprojects is limited (Mok et al. 2015) and the integration of CSR in megaprojects is even more fragmented (Shen et al. 2017; Zeng et al. 2015).

11.2. FUTURE DIRECTIONS

The university-industry collaboration was mutually beneficial and the research contributes to both the conceptual and contextual frames (cf. Figure 2-5) which are summarized below:

- Environmental practices were cultivated and the business objectives were met in SWP based on state of the art sustainability literature and applied research methods.
- Theoretical contributions were made to ecodesign literature in relation to situated learning based on the journal publications and possibly to project management literature in relation to sustainability, although no project specific journals were used.
- The design-based research strategy emphasized the interplay between contextual and conceptual developments in the design of ecodesign solutions.
- The conceptual frame provides opportunities for theory in use for the contextual frame while the latter provides the former opportunities for theory building.

There are many ongoing operational optimizations in terms of waste and energy (cf. 5.2.3). For example, lighting, ventilation, heating are constantly being upgraded in the manufacturing facilitates. The primary focus of this research was organizational transformation (cf. 3.2.3) as it pertains to integrating environment in the design and manufacturing of turbine components. There are significant waste and energy saving potentials in the industrial technologies and processes especially for blade manufacturing. Further, a bigger focus on the project functions is advised as they are responsible for the transport and installation of the turbines and have significantly less action plans defined in comparison to the manufacturing facilities (cf. 5.2.3). Service was omitted from this scope but future actions should also bring more focus to their activities. At both levels Siemens Wind Power should continue to strengthen its efforts around sustainability and align with key business functions such as sales, strategy, technology and procurement.

Further, suppliers and contractors upstream and downstream the manufacturing of turbines have obvious environmental impacts and a deeper analysis into these and their mitigation measures could provide interesting contributions to sustainability discourses in the wind industry. The largest improvement potential is within the systems level (cf. 3.2.3).In relation to this, SWP could also direct future efforts into investigating its extended scope of responsibility and how it can influence other stakeholders and create social value for society. This can be done with more systems and societal-based thinking and through the formation of networks and partnerships. SWP should view itself more as part of a sustainable transition in the energy system otherwise it risks becoming just a turbine supplier and service provider.

Future research scopes should be expanded to the construction and service of wind farm projects in addition to how sustainability is integrated in product portfolio management and megaprojects. Further focus should be directed at how the respective stakeholders are engaged. A more comprehensive investigation on the societal level and stakeholder management strategies are encouraged and this could be done by contrasting the needs of the diverse customer mix such as private owners and cooperatives, utilities, green financers, governments as well as local communities.

Regarding directions for the future of sustainability science, similar industrial based studies may be carried out within large multinationals or project based companies that face similar objectives or stakeholder concerns. Other studies could be carried out to analyse similarities and contrasts between different industries as external drivers and environmental areas of concern are likely to be different in nature. Most importantly, life cycle management and the soft elements such as change management, participation and adaptive learning are highly encouraged as well as a focus on the transitions research and the multi-stakeholder interactions. A final suggestion would be to create a publication strategy that orientates around business oriented, product development and project management journals rather than just sustainability journals, as this is helps to disseminate sustainability literature to wider audiences.

REFERENCES

Ackermann, T., & Söder, L. (2002). An overview of wind energy-status 2002. *Renewable and Sustainable Energy Reviews,* 6, pp.67-128.

Adams, R., Jeanrenaud, S., Bessant, J., Overy, P. & Denyer, D. (2012). Innovating for sustainability: a systematic review of the body of knowledge. London, ON: Network for Business Sustainability.

Adomssent, M. & Godemann, J. (2011). Sustainability communication: an integrative approach. In J. Godemann, & G. Michelsen (Eds.), *Sustainability Communication - Interdisciplinary Perspective and Theoretical Foundations,* pp.27-39. Lüneburg: Springer.

Ahi, P. & Searcy, C. (2015). An analysis of metrics used to measure performance in green and sustainable supply chains. *Journal of Cleaner Production*, 86, pp.360-377.

Aitken, M., Haggett, C. & Rudolph, D. (2014). Wind Farms Community Engagement Good Practice Review. Edinburgh: The University of Edinburgh.

Albino, V., Balice, A. & Dangelico, R.M. (2009). Environmental strategies and green product development: an overview on sustainability-driven companies. *Business Strategy and the Environment*, 18, pp.83–96.

Albino, V., Dangelico, R.M. & Pontrandolfo, P. (2012). Do inter-organizational collaborations enhance a firm's environmental performance? A study of the largest U.S. companies. *Journal of Cleaner Production*, 37, pp.304-315.

Ali, F., Boks, C. & Bey, N. (2016). Design for sustainability and project management literature: a review. *CIRP*, 48, pp.28-33.

Ammenberg, J. & Sundin, E. (2005). Products in environmental management systems: drivers, barriers and experiences. *Journal of Cleaner Production,* 13(4), pp.405–415.

Anderson, J.C., Narus, J.A. & Van Rossum, W. (2006). Customer value propositions in business markets. *Harvard Business Review*, March 2006, pp.90-99.

Andreasen, M.M. & Olesen, J. (1990). The concept of dispositions. *Journal of Engineering Design,* 1(1), pp.17–36.

Andreasen, M.M. & McAloone, T.C. (2008). Applications of the Theory of Technical Systems: Experiences from the 'Copenhagen School'. In *Proceedings of the 2008 Applied Engineering Design Science Workshop* (pp.1-18). Pilsen: University of West Bohemia.

Andriessen, D.G. (2008). Combining design-based research and action research to test management solutions. In B. Boog, M., Slagter, J. Zeelen & J. Preece (Eds.), *Towards Quality Improvement of Action Research: Developing Ethics and* Standards. Rotterdam: Sense Publishers.

Ardente, F., Beccali, M., Cellura, M., & Lo Brano, V. (2008). Energy performances and life cycle assessment of an Italian wind farm. *Renewable and Sustainable Energy Reviews,* 12, pp.200-217.

Argyris, C., Putnam, R. & Smith, D.M. (1985). *Action Science*. San Francisco: Jossey-Bass Inc.

Argyris C. & Schön, D.A. (1978). *Organizational Learning: A Theory of Action Perspective.* Boston: Addison-Wesley Company.

Arnett, E., Huso, M., Schirmacher, M., & Hayes, J. (2011). Altering turbine speed reduces bat mortality at wind-energy facilities. *Frontiers in Ecology and the Environment,* 9(4), pp.209-214.

Aschehoug, S.H., Boks, C. & Storen, S. (2012). Environmental information from stakeholders supporting product development. *Journal of Cleaner Production*, 31, pp.1–13.

Aslani, A. & Mohaghar, A. (2013). Business structure in renewable energy industry: Key areas. *Renewable and Sustainable Energy Reviews,* 27, pp.569-575.

Aso, R. & Cheung, W.M. (2015). Towards greener horizontal-axis wind turbines: analysis of carbon emissions, energy and costs at the early design stage. *Journal of Cleaner Production*, 87, pp.263–274.

Aubrey, C. (2007, January / February). Supply chain: The race to meet demand. *Wind Directions*, pp. 27-34.

AVK & CCeV (2015). *Composites market report 2015. Market developments, trends, outlook and challenges*.

AWEA (American Wind Energy Association) (2015). Anatomy of a wind turbine. Retreived from http://www.awea.org/Resources/Content.aspx?ItemNumber=5083&RDtoken=29819&userID=4379.

Baerwald, E., Edworthy, J., Holder, M., & Barclay, R. (2009). A large-scale mitigation experiment to reduce bat fatalities at wind energy facilities. *Journal of Wildlife Management,* 73, pp.1077-1082.

Balogun, J. & Hailey, V. H. (2004). Exploring Strategic Change, 2nd Ed. London: Pearson Education.

Banerjee, S.B. (2001). Corporate environmental strategies and actions. *Management Decision*, 39(1), pp.36–44.

Barab, S. (2014). Design-based research: a methodological toolkit for engineering change. In K. Sawyer (Eds.), *Handbook of the Learning Sciences*, 2, pp.233-270. Cambridge: Cambridge University Press.

Barab, S., MaKinster, J.G., & Scheckler, R. (2004). Designing system dualities: characterizing an online professional development community. In S. Barab, R. Klin & J. Gray (Eds.), *Designing for Virtual Communities in the Service of Learning*. Cambridge: Cambridge University Press.

Barab, S. & Squire, K. (2004). Design-based research: putting a stake in the ground. *Journal of the Learning Sciences*, 13(1), pp.1-14.

Barquet, A.P.B., Pigosso, D.C.A. & Rozenfeld, H. (2013). Systematic Approach to Formulate PSS Development Project Proposals in the Fuzzy Front End. In H., Meier (Eds.), *Product-Service Integration for Sustainable Solutions,* pp.121–130. Berlin: Springer Publishing.

Baskerville R., Pries-Heje J. & Venable J. (2009). Soft design science methodology. In *Proceedings of DESRIST '09 Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology.* Philadelphia.

Battaglia, M.P. (2008). Nonprobability Sampling. In P.J., Lavrakas (Eds.), *Encyclopaedia of Survey Research Methods*, pp.524–27. Thousand Oaks: SAGE Publications

Baumann, H., Boons, F. & Bragd, A. (2002). Mapping the green product development field: engineering, policy and business perspectives. *Journal of Cleaner Production*, 10, pp.409-425.

Bebbington, J., Brown, J., Frame, B. & Thomson, I. (2007). Theorizing engagement: the potential of a critical dialogic approach. *Accounting, Auditing & Accountability Journal,* 20(3), pp.356–381.

Bell, P. (2004). On the Theoretical Breath of Design-Based Research in Education. *Educational Psychologist,* 39(4), pp.243-254.

Benn, S., Dunphy, D. & Griffiths, A. (2006). Enabling change for corporate sustainability: an integrated perspective. *Journal of Environmental Management*, 13(3), pp.156-165.

Benn, S. & Baker, E. (2009). Advancing sustainability through change and innovation: a co-evolutionary perspective. *Journal of Change Management*, 9(4), pp.383-397.

Bergström, L., Kautsky, L., Malm, T., Rosenberg, R., Wahlberg, M., Åstrand Capetillo, N., & Wilhelmsson, D. (2014). Effects of offshore wind farms on marine wildlife - a generalized impact assessment. *Environmental Research Letters,* 9(3).

Bermejo, R. (2014). Sustainable Development in the Brundtland Report and its distortion. In R., Bermejo (Eds.), *Handbook for a Sustainable Economy*, pp.69-82. Dordrecht: Springer Publishing.

Berns, M., Townend, A., Khayat, Z., Balagopal, B., Reeves, M., Hopkins, M. & Kruschwitz, N. (2009). The Business of Sustainabilities: What it means to managers now. *MIT Sloan Management Review,* 51(1), Fall 2009, pp.1-12.

Bey, N., Hauschild, M.Z. & Mcaloone, T.C. (2013). Drivers and barriers for implementation of environmental strategies in manufacturing companies. *CIRP Annals,* 62(1), pp.43–46.

Biesta, G.J. & Burbules, N.C. (2003). *Pragmatism and Educational Research*. Oxford: Rowman & Littlefield Publishers

Bijker, W.E., Hughes, T.P. & Pinch, P.J. (1987). *The Social Construction of Technological Systems*. Cambridge: MIT Press.

Binder, M. & Clegg, B. (2010). *Sustainable Supplier Management in the Automotive Industry*. New York: Nova Science Publishers, Inc.

Birdwell-Mitchell, E.N. (2016). Collaborative institutional agency: how peer learning in communities of practice enables and inhibits micro-institutional change. *Organization Studies,* 37(2), pp.161-192.

Bogdan, R.C. & Biklen, S.K. (1982). Qualitative Research for Education: An Introduction to Theory and Methods. Boston: Allyn and Bacon.

Böger, L., Sumfleth, J., Hedemann, H. & Schulte, K. (2010). Improvement of fatigue life by incorporation of nanoparticles in glass fibre reinforced epoxy. *Composities Part A: Applied Science and Manufacturing,* 41(10), pp.1419-1424.

Boks, C. (2006). The soft side of ecodesign. *Journal of Cleaner Production*, 14(15-16), pp.1346-1356.

Boland, R.J. & Tenkasi, R.V. (1995). Perspective making and perspective taking in communities of knowing. *Organization Science,* 6(4), pp.350-372

Bolisani, E. & Scarso, E. (2014). The place of communities of practice in knowledge management studies: a critical review. *Journal of Knowledge Management*, 18(2), pp.366 – 381.

Bolton, R., Gustafsson, A., McColl-Kennedy, J.S. & Tse, D. (2014). Small details that make big differences: A radical approach to consumption experience as a firm's differentiating strategy. *Journal of Service Management,* 25(2), pp.253-274.

Bonou, A. (2016). On the shoulders of giants – life cycle based ecodesign applied in the wind energy technologies (Doctoral dissertation). Technical University of Denmark, Management Engineering.

Bonou, A., Laurent, A. & Olsen, S.I. (2016) Life cycle assessment of onshore and offshore wind energy-from theory to application. *Applied Energy,* 180, pp.327-337.

Bonou, A., Olesen, S.I. & Hauschild, M.Z. (2015). Introducing life cycle thinking in product development: a case from Siemens Wind Power. *CIRP Annals*, 64(1), pp.45-48.

Boons, F., Montalvo, C., Quist, J. & Wagner, M. (2013). Sustainable innovation, business models and economic performance: an overview. *Journal of Cleaner Production,* 45, pp.1–8.

Boonstra, J.J. (2004). Dynamics of Organizational Change and Learning. New Jersey: John Wiley & Sons, Ltd.

Borda, O.F. (2006). Participatory (action) research in social theory: origins and challenges. In B., Reason, H., Bradbury (Eds.), *The Handbook of Action Research, Concise Paperback Edition,* pp.27-37. Thousand Oaks: SAGE Publications.

Bosch-Badia, M., Montllor-Serrats, J., & Tarrazon, M. (2013). Corporate Social Responsibility from Friedman to Porter and Kramer. *Theoretical Economics Letters,* 3, pp.11-15.

Bovea, M.D. & Perez-Belis, V. (2012). A taxonomy of ecodesign tools for integrating environmental requirements into the product design process. *Journal of Cleaner Production,* 20(1), pp.61-71.

Bowker, G. & Star, S.L. (2000). *Sorting Things Out: Classification and its Consequence*. Cambridge: MIT Press.

Brady, T., Davies, A. & Gann, D. (2005). Creating value by delivering integrated solutions. *International Journal of Project Management, 23*(5), pp.360-365.

Bratteteig, T. (2003). Making change. Dealing with relations between design and use. (Doctoral dissertation). University of Oslo, Department of Informatics.

Brennan, N., Merkl-Davies, D. & Beelitz, A. (2013). Dialogism in corporate social responsibility communications: conceptualising verbal interaction between organisations and their audiences. *Journal of Business Ethics,* 115, pp.665-679.

Brezet, H. (1997). Dynamics in ecodesign practice. *Industry and Environment*, 20(1-2), pp.21-24.

Brezet, H. & van Hemel, C. (1997). Ecodesign: A Promising Approach to Sustainable Production and Consumption. Paris: United Nations Environmenal Program (UNEP).

Brindley, C. & Oxborrow, L. (2014). Aligning the sustainable supply chain to green marketing needs: a case study. *Industrial Marketing Management,* 43(1), pp.45-55.

Brøndsted, P., Lilholt, H. & Lystrup, A. (2005). Composite materials for wind power turbine blades. *Annual Review of Materials Research,* 35, pp.505-538.

Brones, F., Monteiro de Carvalho, M. & de Senzi Zancul, E. (2014). Ecodesign in project management: a missing link for the integration of sustainability in product development? *Journal of Cleaner Production,* 80, pp.106-118.

Brones, F., Monteiro de Carvalho, M. & de Senzi Zancul, E. (2016). Reviews, action and learning on change management for ecodesign transition. *Journal of Cleaner Production*, 142 (Part 1), pp.8-22.

Brook, J.W. & Pagnanelli, F. (2014). Integrating sustainability into innovation project portfolio management – a strategic perspective. *Journal of Engineering Technology Management*, 34, pp.46-62.

Brown, A.L. (1992). Design experiments: theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences*, 2(2), pp.141-178.

Brown, J.S. & Duguid, P. (1991). Organizational learning and communities of practice: toward a unified view of working, learning and innovation. *Organization Science*, 2, pp.40-57.

Bryman, A. (2012) *Social Research Methods, 4th ed.* Oxford: Oxford University Press.

Bryman, A. (2016). *Social Research Methods, 5th ed.* Oxford: Oxford University Press.

Bryman, A. & Bell, E. (2015). *Business Research Methods, 4th ed.* Oxford: Oxford University Press.

BTM Consult ApS (2015). *World energy market update 2015.*

Buchanan, D.A. & Bryman, A. (2007). Contextualizing methods choice in organizational research. *Organizational Research Methods*, 10, pp.483-501.

Buck, C. (2013, Spring). *A new spin on production.* Pictures of the Future. https://www.siemens.com/innovation/en/home/pictures-of-the-future/archive.html.

Bulleri, F., & Airoldi, L. (2005). Artificial marine structures facilitate the spread of a non-indigenous green alga, Codium fragile ssp. tomentosoides, in the north Adriatic Sea. *Journal of Applied Ecology,* 42, pp.1063-1072.

Burchardt, C. (2012). High definition product lifecycle management decision making framework. In *Engineering, Technology and Innovation (ICE), 2012 18th International ICE Conference on 18-20 June 2012. IEEE, Munich, pp.1–11.*

Burchell, J. & Cook, J. (2006). Assessing the impact of stakeholder dialogue: changing relationships between NGOs and companies. *Journal of Public Affairs,* 6, pp.210-227.

Carlile, P.R. (2002). A pragmatic view of knowledge and boundaries: boundary objects in new product development. *Organization Science*, 13(4), pp.442-455.

Carlile, P.R. (2004). Transferring, translating, and transforming: an integrative framework for managing knowledge across boundaries. *Organization Science,* 15(5), pp.555-568.

Carrillo-Hermosilla, J., del Río, P. & Könnölä, T. (2010). Diversity of eco-innovations: reflections from selected case studies. *Journal of Cleaner* Production, 18, pp.1073–1083.

Carroll, A.B. (2015). Corporate social responsibility: the centrepiece of competing and complementary frameworks. *Organizational Dynamics*, 44, pp.87-96.

Carroll, A.B. & Shabana, K.M. (2010). The business case for corporate social responsibility: a review of concepts, research and practice. *International Journal of Management Reviews*, 12(1), pp.85-105.

Cavallini S., Soldi, R., Friedl, J. & Volpe, M. (2016). *Using the Quadruple Helix Approach to Accelerate the Transfer of Research and Innovation Results to Regional Growth.* European Union.

Chan, H., He, H. & Wang, W. (2012). Green marketing and its impact on supply chain management in industrial markets. *Industrial Marketing Management,* 41, pp.557-562.

Charter, M. (2001) Managing Ecodesign. In M., Charter & U. Tischner (Eds.), *Sustainable Solutions: Developing Products and Services for the Future.* Sheffield: Greenleaf Publishing.

Charter, M., Young, A., Kielkiewicz-Young, A. & Belmane, I. (2001). Integrated product policy and eco-product development. In M., Charter & U. Tischner (Eds.), *Sustainable Solutions: Developing Products and Services for the Future.* Sheffield: Greenleaf Publishing.

Cherrington, R., Goodship, V., Meredith, J., Wood, B.M., Coles, S.R., Vuillaume, A., Feito-Boirac, A., Spee, F. & Kirwan, K. (2012). Producer responsibility: defining the incentive for recycling composite wind turbine blades in Europe. *Energy Policy,* 47, pp.13-21.

Chertow, M. R. (2001). The IPAT equation and its variants; changing views of technology and environmental impact. *Journal of Industrial Ecology*, 4(4), pp.13-29.

Chu, T. & Lee, Y. (2014). Collaborations across knowledge boundary: an e-learning case. *PACIS 2014 Proceedings, 155.*

Cobb, P., Confrey, J. diSessa, A., Lehrer, R. & Schauble, L. (2003). Design Experiments in Educational Research. *Educational Researcher*, 32(1), pp.9-13.

Coch, L. & French, J. (1948). Overcoming resistance to change. *Human relations* 1, pp.512-33.

Coenen, F., Huitema, D., O'Toole L.J. (1998). *Participation and the Quality of Environmental Decision Making.* New York: Springer Publishing.

Coghlan, D. & Coughlan, P. (2010). Notes toward a philosophy of action learning research. *Action Learning: Research and Practice*, 7(2), pp.193-203.

Cohen-Rosenthal, E. (2000). A walk on the human side of industrial ecology. *American Behavioural Scientist*, 44(2), pp.245-264.

Cole, R., Purao, S., Rossi, M. & Sein, M. (2005). Being proactive: where action research meets design research. In *Proceedings of the Twenty-Sixth International Conference on Information Systems, Las Vegas,* pp.325-336.

Collins, A. (1992). Toward a Design Science of Education. In E. Scanlon & T. O'Shea (Eds.), *New Directions in Educational Technology*, pp.15-22. New York: Springer Publishing.

Conti-Ramsden, J. & Dyer, K. (2015). Materials innovations for more efficient wind turbines. *Renewable Energy Focus,* 16(5-6), pp.132-133.

Cooper, A. (2009). *Two-way communication: A win–win model for facing activist pressure: A case study on McDonalds and Unilever's responses to Greenpeace.* Indiana: Ball State University.

Cordery, J.L., Cripps, E., Gibson, C.B., Soo, C., Kirkman, B.L. & Mathieu, J.E. (2015). The operational impact of organizational communities of practice: a Bayesian approach to analysing organizational change. *Journal of Management,* 41(2), pp.644-664.

Cowell, R., Bristow, G., & Munday, M. (2011). Acceptance, acceptability and environmental justice: the role of community benefits in wind energy development. *Journal of Environmental Planning and Management,* 54(4), pp.539-557.

Cox, A. (2005). what are communities of practice? A comparative review of four seminal works. *Journal of Information Science*, 31(6), pp.527-540.

Crane, A. & Livesey, S. (2003). Are You Talking To Me? Stakeholder Communication and the Risks and Rewards of Dialogue. In J. Andriof, S. Waddock, B. Husted, & S. Sutherland Rahman (Eds.), *Unfolding Stakeholder Thinking 2: Relationships, Communication, Reporting and Performance,* pp.39-52. Sheffield: Greenleaf Publishing.

Creswell, J.W. (2007). Qualitative Inquiry and Research Design: Choosing Among Five Approaches, 2nd ed. Thousand Oaks: SAGE Publications.

Creswell, J.W. (2009). *Research Design: Qualitative, Quantitative, And Mixed Methods Approaches*, *3rd ed*. Thousand Oaks: SAGE Publications.

CSE. (2007). *The Protocol for Public Engagement with Proposed Wind Energy Developments in England. A report for the Renewables Advisory Board and DTI.* Centre for Sustainable Energy. [Retreived from http://www.berr.gov.uk/files/file38708.pdf]

Curran, M.A. (2014). Strengths and Limitations of Life Cycle. In W. Klöpffer (Eds.), *Background and Future Prospects in Life Cycle Assessment,* pp.189-206. London: Springer Publishing.

Dai, K., Bergot, A., Liang, C., Xiang, W., & Huang, Z. (2015). Environmental issues associated with wind energy - A review. *Renewable Energy,* 75, pp.911-921.

Daub, C., Karlsson, Y. & Stiller, S. (2005). The growing importance of stakeholder dialogues in generating knowledge and realizing sustainable development. Whose business? What ethics? *Proceedings of the 9th annual conference of the European Business Ethics Network – UK Association (EBEN-UK) and the 7th Ethics and HRM Conference.* Royal Holloway: University of London.

Davies, A., Brady, T. & Hobday, M. (2007). Organizing for solutions: systems seller vs systems integrator. *Industrial Marketing Management*, 36(2), pp.183-193.

de Vries, E. (2015a, December 28). *Turbines of the year: Offshore turbines* Windpower Monthly. http://www.windpowermonthly.com/article/1377329/turbines-year-offshore-turbines.

de Vries, E. (2015b, December 28). *Turbines of the year: Onshore turbines* Windpower Monthly. http://www.windpowermonthly.com/article/1377328/turbines-year-onshore-turbines-3mw-plus.

Dede, C. (2004). If design-based research is the answer, what is the question? A Commentary on Collins, Joseph, and Bielaczyc; diSessa and Cobb; And Fishman, Marx, Blumenthal, Krajcik, and Soloway in the JLS Special Issue on Design-Based Research. *The Journal of the Learning Sciences,* 13(1), pp.105–114.

Dekoninck, E.A., Domingo, L., O'Hare, J.A., Pigosso, D.C.A., Reyes, T. & Troussier, N. (2016). Defining the challenges for ecodesign implementation in companies: development and consolidation of a framework. *Journal of Cleaner Production*, 135, pp.410-425.

Del Borghi, A. (2012). Editorial: LCA and communication-environmental product declaration. *International Journal of Life Cycle Assessment*, 18, pp.293-295.

Del Rosario, V. & Goh, K. (2007). Community Stakeholder Management in Wind Energy Development Projects. A Planning Approach (Master’s dissertation). Umeå University, Umeå School of Business and Economics.

Dentoni, D. & Bitzer, V. (2013). Dealing with wicked problems: managing corporate social responsibility through multi-stakeholder initiatives. *Paper Presented at the Journal of Management Studies Workshop “Managing for Corporate Social Responsibility”, Copenhagen (Denmark), 23-25 May 2013.*

Dentoni, D. & Bitzer, V. (2015). The role(s) of universities in dealing with global wicked problems through multi-stakeholder initiatives. *Journal of Cleaner Production,* 106, pp.68-78.

Denzin, N.K. (1978). Sociological Methods: A Sourcebook. New York: McGraw-Hill.

Depoe, S., Delicath, J. & Aepli Elsenbeer, M. (2004). *Communication and public participation in environmental decision making.* New York: State University of New York Press.

Dernbach, J.C. (2002). Sustainable development: now more than ever. *Environmental Law Reporter*, 32(1).

Deutz, P., Mcguire, M. & Neighbour, G. (2013). Ecodesign practice in the context of a structured design process: an interdisciplinary empirical study of UK manufacturers. *Journal of Cleaner Production*, 39, pp.117–128.

Dewey, J. (1929). The sources of a science of education. In J. Dewey (Eds.), *The Later Works (1925-1953),* 5, pp.1-40. Carbondale: Southern Illinois University Press.

Dewey, J. (1931). The development of American pragmatism. In J. Dewey (Eds.), *Philosophy and Civilization.* New York: Minton, Balch & Co.

Dolan, S., & Heath, G. (2012). Life Cycle Greenhouse Gas Emissions of Utility-Scale Wind Power. Systematic Review and Harmonization. *Journal of Industrial Ecology,* 16.

Doppelt, B. (2012). *The Power Of Sustainable Thinking: How to Create a Positive Future for the Climate, the Planet, your Organization and your Life*. Abingdon-on-Thames: Routledge

DTU (Technical University of Denmark) (2016). *Stakeholder Management in Wind Power Projects.* http://apppm.man.dtu.dk/index.php/Stakeholder_Management_in_Wind_Power_Projects#Stakeholders_and_Stakeholder_Management.

Easterday, M.W., Rees Lewis, D. & Gerber, E. M. (2014). Design-based research process: problems, phases, and applications. *In Proceedings of the International Conference of the Learning Sciences, June 23-27, 2014, Colorado, USA pp.317-324.*

Eberl, U. (2011). A Holistic Approach to Communicating Innovations: Siemens and Its Environmental Portfolio. In M., Hülsmann & N. Pfeffermann (Eds.), *Strategies and Communications for Innovations*. Berlin: Springer Publishing

Eco-innovation Observatory (2013). *Europe In Transition: Paving The Way To A Green Economy Through Eco-Innovation. Annual Report 2012.*

Ehrlich, P.R. (2014) Human impact: the ethics of I=PAT. *Ethics in Science and Environmental Politics*, 14, pp.11-18.

Ehrlich, P.R. & Holdren, J.P. (1972). A bulletin dialogue on "the closing circle," critique. *Bulletin of the Atomic Scientists*, 28(5), pp.16-27.

Eisenhardt, K. & Graebner, M. (2007). Theory building from cases: opportunities and challenges. *Academy of Management Journal, 50*(1), pp.25-32.

Eisner, E.W. (1993). Reshaping assessment in education: some criteria in search of practice. *Journal of Curriculum Studies*, 25(3), pp.219–33.

Elkington, J. (1994). Towards the sustainable corporation: win-win-win business strategies for sustainable development. *California Management Review*, 36(2), pp.90-100.

Elkington, J. (2006). Governance for sustainability. *Corporate Governance: An International Review*, 14(6), pp.522-529.

Elkington, J. (2014). *Get Ready for the Breakthrough Decade...* London: Volans Ventures Ltd.

Elkington, J., Fledman, A., Høgsted, A.H., Johnson, R., Lakha, S., Lim, S., Love, C. & Lye, G. (2015). *The Stretch Agenda. Breakthrough in the Boardroom.* London: Volans Ventures Ltd.

Elkington, J. & Braun, S. (2013). *Breakthrough: Business Leaders, Market Revolutions.* London: Volans Ventures Ltd.

Ellen MacArthur Foundation (2017). CE100 https://www.ellenmacarthurfoundation.org/ce100.

Engelken, M., Römer, B., Drescher, M., Welpe, I. & Picot, A. (2016). Comparing drivers, barriers, and opportunities of business models for renewable energies: A review. *Renewable and Sustainable Energy Reviews, 60*, pp.795-809.

ENS. (2017, August 1). Eksisterende havvindmølleparker og aktuelle projekter. *Energistyrelsen*. https://ens.dk/ansvarsomraader/vindenergi/eksisterende-havvindmoelleparker-og-aktuelle-projekter.

Erlandsson, J. & Tillman, A. (2009). Analysing influencing factors of corporate environmental information collection, management and communication. *Journal of Cleaner Production*, 17(9), pp.800–810.

European Commission (2011a). *Roadmap to a resource efficient Europe*.

European Commission (2011b). *Technology Map of the European Strategic Energy Technology Plan.* Petten: European Commission - Joint Research Center - Institute for Energy and Environment.

European Commission (2014). *Ecodesign Your Future.*

European Commission (2016). *European Sustainable Consumption and Production Policies.* http://www.ec.europa.eu/environment/eussd/escp_en.htm.

European Commission (2017a). *Resource Efficiency*. http://www.ec.europa.eu/environment/resource_efficiency/index_en.htm.

European Commission (2017b). Circular Economy Strategy. http://www.ec.europa.eu/environment/circular-economy/index_en.htm.

European Union (2016). *Using the Quadruple Helix Approach to Accelerate the Transfer of Research and Innovation Results to Regional Growth.* Eurpean Union - Committee of the Regions.

EWEA (European Wind Energy Association) (2009a). *The Economics of Wind Energy.*

EWEA (European Wind Energy Association) (2009b). Part V: Environmental Issues. In *Wind energy - the facts. A guide to the technology, economics and future of wind power.*

EWEA (European Wind Energy Association) (2009c). *Pure Power. Wind Energy Targets for 2020 and 2030.*

EWEA (European Wind Energy Association) (2012). *Research Note Outline On Recycling Wind Turbine Blades.*

EWEA (European Wind Energy Association) (2014a). *Wind in Power. 2013 European statistics.*

EWEA (European Wind Energy Association) (2014b). *Building a Stable Future. Annual Report 2013.*

EWEA (European Wind Energy Association) (2014c). *Saving water with wind energy.* Brussels: European Wind Energy Association.

EWEA (European Wind Energy Association) (2016). *Wind in Power. 2015 European statistics.*

Flyvbjerg, B. (2014). What you should know about megaprojects and why: an overview. *Journal of Project Management,* 45 (2), pp.6-19.

Foster, D. & Jonker, J. (2005). Stakeholder relationships the dialogue of engagement. *Corporate Governance*, 5(5), pp.51–57.

Frankl, P. & Rubik, F. (2000). *Life Cycle Assessment in Industry and Business. Adoption Patterns, Applications and Implications*. Dordrecht: Springer Publishing.

Frideres, J.S. (1992). Participatory research: an illusionary perspective. In J.S. Frideres (Eds.), *A World Of Communities: Participatory Research Perspectives.* North York: Captus University Publications.

Frow, P. M.-K., Hilton, T., Davidson, A., Payne, A. & Brozovic, D. (2014). Value propositions: a service ecosystems perspective. *Marketing Theory*, 14(3), pp.327-351.

Gabriel, C. (2016). What is challenging renewable energy entrepeneurs in developing countries? *Renewable and Sustainable Energy Reviews, 64*, pp.362-371.

Gamesa (2013). *Ecowind - LCA of 1 kWh generated by a Gamesa onshore wind farm G90-2.0 MW.* Zamudio: Gamesa.

Gamesa (2014). *LCA of 1 kWh energy generated by Gamesa G114-2.0 MW onshore wind farm.* Zamudio: Gamesa.

Garrett, P., & Rønde, K. (2013). Life cycle assessment of wind power: comprehensive results from a state-of-the-art approach. *International Journal of Life Cycle Assessment,* 18, pp.37-48.

Gasch, R., & Twele, J. (2012). *Wind Power Plants. Fundamentals, Design, Construction and Design, 2nd ed.*. London: Springer Publishing.

Gassmann, O. & Schweitzer, F. (2014). Managing the unmanageable: the fuzzy front end of innovation. In O., Gassmann & F. Schweitzer (Eds.), *Management of the Fuzzy Front End of Innovation,* pp.3–14. New York: Springer Publishing.

Gaziulusoy, I.A. (2010). A scenario method and a workshop process for product development teams (Doctoral dissertation). The University of Auckland.

Gaziulusoy, I.A. & Brezet, H. (2015). Design for system innovations and transitions: a conceptual framework integrating insights from sustainability science and theories of system innovations and transitions. *Journal of Cleaner Production,* 108 (Part A), pp.558-568.

Geels, F.W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy,* 31, pp.1257–1274.

GenVind (2016). Results. http://GenVind.net/Results/Results.htm.

Georg, S. & Fussel, I. (2000). Making sense of greening and organizational change. *Business Strategy and the Environment*, 9, pp.175-85.

Gergen, K.J. (1999). *An Invitation to Social Construction*. London: SAGE Publications.

Gipe, P. (1995). *Wind Energy Comes of Age, 1st ed.*. New York: Wiley.

Gladwin, T.N. (1993). The meaning of greening: a plea for organizational theory. In K., Fischer & J., Schot (Eds.), *Environmental Strategies for Industry – International Perspectives on Research Needs and Policy Implications.* Covelo: Island press.

Glahn, J. & Heydenreich, K. (2001). Steps towards sustainable development at Brødrene Hartmann A / S. *Corporate Environmental Strategy,* 8(2), pp.186–192.

Godemann, J. & Michelsen, G. (2011). Sustainability Communication. Interdisciplinary Perspectives and Theoretical Foundations. New York: Springer Publishing.

Goldkuhl, G. (2013). Action research vs. design research: using practice research as a lens for comparison and integration. In IT Artefact Design & Work Practice Improvement (ADWI-2013). http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-103228.

Gomez-Briceño, D., De Jong, M., Drage, T., Falzetti, M. Hedin, N. & Snijkers, F. (2012). *Strategic Energy Technology Plan.* European Commission.

González-Benito, J. & González-Benito, Ó. (2006). A review of determinant factors of environmental proactivity. *Business Strategy and the Environment,* 15(2), pp.87–102.

Gosling, J., Jia, F., Gong, Y. & Brown, S. (2014). The role of supply chain leadership in the learning of sustainable practice: toward an integrated framework. *Journal of Cleaner Production*, 137, pp.1458-1469.

Graetz, F. & Smith, A.C.T. (2010). Managing organizational change: a philosophies of change approach. *Journal of Change Management*, 10(2), pp.135-154.

Gray, B. & Stites, J. (2013). *Sustainability through Partnerships: Capitalizing on Collaboration.* Network for Business Sustainability.

Grekova, K., Calantone, R.J., Bremmers, H.J., Trienekens, J.H. & Omta, S.W.F. (2015). How environmental collaboration with suppliers and customers influences firm performance: evidence from Dutch food and beverage processors. *Journal of Cleaner Production*, 112(3), pp.1861-1871.

Griffith, D. (2002). The role of communication competencies in international business relationship development. *Journal of World Business, 37*, pp.256-265.

Grin, J., Rotmans, J., Schot, J., Loorbach, D. & Geels, F.W. (2010). Transitions to Sustainable Development; New Directions in the Study of Long Term Transformative Change. Abingdon-on-Thames: Routledge.

Gross, C. (2007). Community perspective of wind energy in Australia: the application of a justice and community fairness framework to increase social acceptance. *Energy Policy,* 35(5), pp.2727-2736.

Guezuraga, B., Zauner, R., & Pölz, W. (2012). Life cycle assessment of two different 2 MW class wind turbines. *Renewable Energy,* 37, pp.37-44.

Guzzo, R.A., Jette, R.D. & Katzell, R.A. (1985). The effects of psychologically based intervention programs on worker productivity: a meta-analysis. Personal Psychology, 38(2), pp.275–291.

GWEC (Global Wind Energy Council) (2014). Global Wind Energy Outlook: 2000 gigawatts by 2030 http://www.gwec.net/publications/global-wind-energy-outlook/global-wind-energy-outlook-2014/.

GWEC (Global Wind Energy Council) (2015). Wind in Numbers http://www.gwec.net/global-figures/wind-in-numbers/.

GWEC (Global Wind Energy Council) (2016a). *Global Wind Report - Annual Market Update.* Brussels: Global Wind Energy Council.

GWEC (Global Wind Energy Council) (2016b). *Global Wind Energy Outlook.* Brussels: Global Wind Energy Council.

GWO (Global Wind Organization) (2017). Global Wind Organization > About http://www.globalwindsafety.org/gwo/about.html.

Haapala, K., & Prempreeda, P. (2014). Comparative life cycle assessment of 2.0 MW wind turbines. *International Journal of Sustainable Manufacturing,* 3(2).

Habermas, J. (1982). Reply to my critics. In J. Thompson, & D. Held, Habermas: *Critical Debates,* pp.219-283. London: Macmillan Press.

Halme, M. (1997). Developing an environmental culture through organizational change and learning. In Welford, R. (Eds.), *Corporate Environmental Management 2: Culture And Organizations*. London: Earthscan Publications Ltd.

Hanna, M.D., Newman, W.R. & Johnson, P. (2000). Linking operational and environmental improvement through employee involvement. *International Journal of Operations and Production Management,* 20(2), pp.148–165.

Hendry, C. (1996). Understanding and creating whole organizational change through learning theory. Human Relations, 49(5), pp.621-641.

Hernáez, O.R. & Campos, E.B. (2011). *Handbook of Research on Communities of Practice for Organizational Management and Networking: Methodologies for Competitive Advantage.* Hershey: IGI Global.

Hevner, A.R. (2007). A three cycle view of design science research. *Scandinavian Journal of Information Systems*, 19(2) Article 4.

Hevner A.R., March S.T., Park J. & Ram S. (2004). Design science in information systems research. *MIS Quarterly,* 28(1), pp.75-105.

Hildreth, P. & Kimble, C. (2002). The duality of knowledge. *Information Research,* 8(1), paper no. 142. http://InformationR.net/ir/8-1/paper142.html.

Hobday, M., Rush, H. & Tidd, J. (2000). Innovation in complex products and system. *Research Policy*, 29(7), pp.793-804.

Hoffman, A.J. & Georg, S. (2013). A history of research on business and the natural environment: conversations from the field. In S., Georg & A.J., Hoffman (Eds.), *Business and the Natural Environment: Critical Perspectives on Business and Management.* Abingdon-on-Thames: Routledge.

Holgaard, J.E. (2003). Miljøkommunikation i og imellem virksomheder. Aalborg Universitet, Institut for Samfundsudvikling og Planlægning.

Holgaard, J. E., Remmen, A. & Jørgensen, T. H. (2007a). LCM – intentional strategy or patchwork of practices?. Aalborg Universitet, Institut for Samfundsudvikling og Planlægning.

Holgaard, J.E., Remmen, A. & Jørgensen, T. H. (2007b). Organizational learning and environmental communication: the momentum of environmental management (Doctoral dissertation). Aalborg Universitet, Institut for Samfundsudvikling og Planlægning.

Holmström, J., Ketokivi, M. & Hameri, A.P. (2009). Bridging practice and theory: A design science approach. *Decision Sciences*, 40(1), pp.65-87.

Holst, J.C., Mueller, K. & Uebelhoer, K. (2011). Sustainable Lifecycle Engineering at Siemens AG. *LCM conference proceedings.*

Huemann, M. & Silvius, G. (2105). Call for papers: International Journal of Project Management Theme: "Managing projects & sustainability". *International journal of project management*, 33, pp.719-720.

IEA (2010). *Projected Costs of Generating Electricity.* International Energy Agency.

IEA (2015). *Projected Costs of Generating Electricity.* International Energy Agency.

IEA (2016). *IEA WIND - 2015 Annual report.* International Energy Agency.

Ing (2002, January 2). *Danske vindmøllefabrikanter vil selv producere vinger.* Ingeniøren. http://ing.dk/artikel/danske-vindmollefabrikanter-vil-selv-producere-vinger-44983.

Innovation Fund Denmark (2016). Industrial PhD. http://www.innovationsfonden.dk/en/application/erhvervsphd.

IPCC (Intergovernmental Panel on Climate Change) (2007). *Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge: Cambridge University Press.

IRENA (2012). *RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES.* Bonn: International Renewable Energy Agency.

ISO (2002). *ISO/TR 14062:2002. Environmental management - Integrating environmental aspects into product design and development.* Geneva: International Organization for Standardization.

ISO (2006). *DS/EN ISO 14040:2006 Environmental management - life cycle assessment – principles and framework.* Geneva: International Organization for Standardization.

ISO (2010). *ISO 14063:2010 Environmental management - Environmental communication - Guidelines and examples. The International Organization for Standardization.* Geneva: International Organization for Standardization.

ISO (2011). *ISO 14006:2011 Environmental management systems — Guidelines for incorporating ecodesign.* Geneva: International Organization for Standardization.

ISO (2015). *ISO 14001:2015. Environmental management systems - Requirements with guidance for use.* Geneva: International Organization for Standardization.

ISO (2016). The ISO Survey of Management System Standard Certifications 2015. Executive Summary. https://www.iso.org/files/live/sites/isoorg/files/standards/conformity_assessment/certification/doc/survey_executive-summary.pdf.

Jackson, T. (2009). Prosperity without growth: economics for a finite planet. London: Earthscan Publications Ltd.

Janssen, L., Lacal Arántegui, R., Brøndsted, P., Gimondo, P., Klimpel, A., Johansen, B., & Thibaux, P. (2012). *Scientific assessment in support of the materials roadmap enabling low carbon energy technologies: Wind energy.* European Commission, Joint Research Centre, Institute for Energy and Transport.

Jensen, J.P., Kastbjerg, S., Lei, M. & Hansen, M.K. (2016). *GenVind.net.* http://GenVind.net/Results/Results.htm.

Jensen, J.P. & Remmen, A. (2017). Enabling circular economy through product stewardship. *Procedia Manufacturing,* 8, pp.377-384.

Jensen, J.P. & Skelton, K. (2017). Wind turbine blade recycling: experiences, challenges and possibilities in a circular economy. *In review*.

Johansen, T. & Nielsen, A. (2011). Strategic stakeholder dialogues: a discursive perspective on relationship building. *Corporate Communications: An International Journal,* 16(3), pp.1356-3289.

Johansson, G. (2002). Success factors for integration of ecodesign in product development: a review of state-of-the-art. *Management of Environmental Quality: An International Journal,* 13(1), pp.98-107.

Johansson, G., Greif, A. & Fleischer, G. (2007). Managing the design/environment interface: studies of integration mechanisms. *International Journal of Production Research*, 45(18-19), pp.4041-4055.

Johansson, G. & Sundin, E. (2014). Lean and green product development: two sides of the same coin? *Journal of Cleaner Production*, 85(15), pp.104-121.

Johnson, H. & Wilson, G. (1999). Institutional sustainability as learning. *Development in Practice,* 9(1-2), pp.43-55.

Johnston, W., Leach, M. & Liu, A. (1999). Theory testing using case studies in business-to-business research. *Industrial Marketing Management,* 28(3), pp.201-213.

Junquera, B., Del Brío, J.Á. & Fernández, E. (2012). Clients' involvement in environmental issues and organizational performance in businesses: an empirical analysis*. Journal of Cleaner Production*, 37, pp.288–298.

Kaldellis, J.K. & Zafirakis, D. (2011). The wind energy (r)evolution: a short review of a long history. *Renewable Energy*, 36, pp.1887–1901.

Karlsson, C. (2009). *Researching Operations Management.* New York: Routledge.

Karlsson, R., Backman, M. & Djupenström, A. (2010). Sustainability considerations and triple-helix collaboration in regional innovation systems. In J., Sarkis, J., Cordeiro, D., Vazquez Brust, D. (Eds.), *Facilitating Sustainable Innovation through Collaboration. A Multi-Stakeholder Perspective*. New York: Springer Publishing.

Keitsch, M. (2012). Sustainable design: a brief appraisal of its main concepts. *Sustainable Development,* 20(3), pp.180-188.

Kelly, A.E. (2004). Design research in education: yes, but is it methodological? *Journal of the Learning Sciences*, 13(1), pp.115-128.

Kemp, R., Loorbach, D. & Rotmans, J. (2007). Transition management as a model for managing processes of co-evolution towards sustainable development. *The International Journal of Sustainable Development and World Ecology*, 14(1), pp.78–91.

Keogh, P.D. & Polonsky, M.J. (1998). Corporate commitment to the natural environment: issues in a team approach. In J., Moxan & P.A., Strachan (Eds.), *Managing Green Teams: Environmental Change in Organisations and Networks*. Sheffield: Greenleaf Publishing Ltd.

King, W.R. (2009). Knowledge management and organizational learning. *Annals of Information Systems,* 4. New York: Springer Publishing.

Klick, H. (2010). Public understanding of and support for wind power in the United States. *Renewable Energy,* 35(7), pp.1585-1591.

Knight, P. & Jenkins, J.O. (2009). Adopting and applying eco-design techniques: a practitioner's perspective. *Journal of Cleaner Production,* 17, pp.549-558.

Kotler, P. (2011). Reinventing marketing to manage the environmental imperative. *Journal of Marketing, 75*, pp.132-135.

Koziol, K. et al., 2007. High-performance carbon nanotube fiber. *Science,* 318(5858), pp.1892-1895.

Kraaijenhagen, C., van Oppen, C. & Bocken, N. (2016). *Circular Business. Collaborate and Circulate. Circular Collaboration.*

Krewitt, W., Nienhaus, K., Klessmann, C., Capone, C., Stricker, E., Graus, W., . . . Samadi, S. (2009). *Role and Potential of Renewable Energy and Energy Efficiency for Global Energy Supply.* German Federal Environment Agency.

Kuhn, T. & Deetz, S. (2008). Critical theory and corporate social responsibility: Can/should we get beyond cynical reasoning? In A., Crane, D., Matten, A., McWilliams, J., Moon, & D., Siegel (Eds.), *The Oxford Handbook of Corporate Social Responsibility* (pp.173–196). Oxford: Oxford University Press.

Kuhndt, M. (2004). Sustainable business development. In E.U., von Weizsäcker, C., Liedtke & J., Seiler-Hausmann (Eds.), *Eco-efficiency and Beyond. Towards the Sustainable Enterprise*. Sheffield: Greenleaf Publishing.

Kvale, S. (1983). The qualitative research interview - a phenomenological and a hermeneutical mode of understanding. *Journal of Phenomenological Psychology,* 14(1-2), pp.171-196.

Kvale, S. (1996). *Interviews: An Introduction to Qualitative Research Interviewing.* Thousand Oaks: SAGE Publications.

Laasch, O. & Conaway, R. (2016). Responsible Business. The Textbook for Management Learning, Competence and Innovation. London: Greenleaf Publishing.

Larsen, K. (2009, January/February). Recycling wind. *REINFORCEDplastics*, pp. 20-25.

Lave, J. & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation.* Cambridge: Cambridge University Press.

Ledec, G., Rapp, K., & Aiello, R. (2011). *Greening the Wind.* Herndon: World Bank Publications.

Lee, A. (2007). Action is an artefact: what action research and design science offers each other. In N., Kock N, (Eds.), *Information Systems Action Research. An Applied View of Emerging Concepts and Methods*. New York: Springer Publishing.

Lee, K.H. & Kim, J.W. (2011). Integrating suppliers into green product innovation development: an empirical case study in the semiconductor industry. *Business, Strategy and the Environment,* 20(8), pp.527-538.

Lenferink, S., Tillema, T. & Arts, J. (2013). Towards sustainable infrastructure development through integrated contracts: experiences with inclusiveness in Dutch infrastructure projects. *International Journal of Project Management*, 31, pp.615–627.

Leonhard, S., Stenberg, C., & Støttrup, J. (2011). *Effect of the Horns Rev 1 offshore wind farm on fish communities.* Kongens Lyngby: DTU Aqua.

Lewin, K. (1946). Action research and minority problems. *Journal of Social Issues,* 2(4), pp.34-46.

Li, J., Zeng, X. & Stevels A. (2014). Ecodesign in consumer electronics: past, present and future. *Critical Reviews in Environmental Science and Technology,* 45(8), pp.840-860.

Liinamaa, J.V., Hurmerinta, A., Ivanova-gongne, M., Luotola, H. & Gustafsson, M. (2016). Performance-based and functional contracting in value-based solution selling. *Industrial Marketing Management, 59*, pp.37-49.

Lincoln, Y.S., Lynham, S.A. & Guba, E.G. (2011). Paradigmatic controversies, contradictions, and emerging confluences, revisited. In N.K., Denzin & Y.S., Lincoln (Eds.), *The SAGE Handbook of Qualitative Research, 4th ed*., pp.97–128. Thousand Oaks: SAGE Publications.

Lindahl, M. & Ekermann, S. (2013). Structure for categorization of ecodesign methods and tools. In A.Y.C., Nee, B., Song & S.K., Ong, (Eds.), *Re-engineering Manufacturing for Sustainability*. New York: Springer Publishing.

Lindeboom, H., Kouwenhoven, H., Bergman, M., Bouman, S., Brasseur, S., Daan, R., . . . van Hal, R. (2011). Short-term ecological effects on an offshore wind farm in the Dutch coastal zone; a compilation. *Environmental Research Letters,* 6(3).

Lindgreen, A., Swaen, V. & Johnston, W. (2009). United States of America: a snapshot of US practices. In S., Idowu & W., Filho (Eds.), *Global Practices of Corporate Social Responsibility,* pp.251-272. Berlin: Springer Publishing.

Lindhqvist, T. (2000). Extended producer responsibility in cleaner production: policy principle to promote environmental improvements of product systems. (Doctoral dissertation). Lund University.

Little, A.D. (2005). *The innovation high ground: how leading companies are using sustainability-driven innovation to win tomorrow's customers.*

Loorbach, D., van Bakel, J., Whiteman, G. & Rotmans, J. (2009). Business strategies for transitions to sustainable systems. *Business, Strategy and the Environment,* 19(2), pp.133-146.

Loorbach, D. & Wijsman, K. (2013). Business transition management: exploring a new role for business in sustainability transitions. *Journal of Cleaner Production*, 45, pp.20-28.

Löwgren, J. & Stolterman, E. (2007). *Thoughtful Interaction Design: A Design Perspective on Information Technology.* Cambridge: The MIT Press.

Lozano, R. (2012). Orchestrating organizational changes for corporate sustainability: overcoming barriers to change. *Green. Manag. Int.,* 57, pp.43-64.

Lui, P.B. (2017). Wind turbine blade waste in 2050. *Waste Management,* 62, pp.229-240.

Luyet, V., Schlaepfer, R., Parlange, M.B. & Buttler, A. (2012). A framework to implement stakeholder participation in environmental projects. *Journal of Environmental Management,* 111, pp.213–219.

Maaninen-Olsson, E., Wismén, M. & Carlsson, S.A. (2006). Knowledge integration and the meaning of boundary activities. *Submitted to OLKC 2006 Conference at the University of Warwick. Coventry on 20-22 March 2006*. https://www2.warwick.ac.uk/fac/soc/wbs/conf/olkc/archive/olkc1/papers/320_olsson.pdf.

MacDonald, E.F. & She, J. (2015). Seven cognitive concepts for successful eco-design. *Journal of Cleaner Production,* 92, pp.23-36.

Mackenzie, D. (1997). *Green Design: Design for the Environment, 2nd ed*. London: Laurence King.

Mægaard, P., Krenz, A., & Palz, W. (2013). *Wind Power for the World: The Rise of Modern Wind Energy* (2nd ed.). Pan Stanford Publishing.

Magnusson, T. (2000). Eco-design and product innovation. Managing incremental and radical change for environmental compliance (Licentiate thesis). Linköpings University.

MAKE Consulting (2015). *Global wind turbine O&M 2014.*

Mangi, S., & Mangi, S. (2013). The Impact of Offshore Wind Farms on Marine Ecosystems: A Review Taking an Ecosystem Services Perspective. *Proceedings of IEEE,* 101(4), pp.999-1009.

Mann, J., & Teilmann, J. (2013). Environmental Impact of Wind Energy. *Environmental Research Letters*, 8.

Marcelino-Sádaba, S., González-Jaen, L.F. & Pérez-Ezcurdia, A. (2015). Using project management as a way to sustainability. From a comprehensive review to a framework definition. *Journal of Cleaner Production*, 99, pp.1-16.

Martens, M.L. & Carvalho, M.M. (2015). The challenge of introducing sustainability into Project Management function: multiple-case studies. *Journal of Cleaner Production,* 117, pp.29-40.

Martínez, E., Sanz, F., Pellegrini, S., Jimenéz, E., & Blanco, J. (2009). Life cycle assessment of a multi-megawatt wind turbine. *Renewable Energy,* 34(3), pp.667-673.

Matos, S. & Silvestre, B. (2013). Managing stakeholder relations when developing sustainable business models: the case of the Brazilian energy sector. *Journal of Cleaner Production,* 45, pp.61-73.

McAloone, T.C. & Bey, N. (2009). *Environmental Improvement through Product Development: A Guide.* Copenhagen: Danish Environmental Protection Agency.

McKenney, S. & Reeves, T.C. (2012). *Conducting Educational Design Research*. London: Routledge.

McLaren Loring, J. (2007). Wind energy planning in England, Wales and Denmark: Factors influencing project success. *Energy policy,* 35(4), pp.2648-2660.

Megavind (2016). *Strategies for Extending the Useful Lifetime of a Wind Turbine,* Copenhagen: Danish Wind Association.

Meimeth, M. & Robertson, J. (2012). *Sustainable Development - How to bridge the Knowledge-Action Gap?* Baden: Nomos.

Mikkelsen, L., Mouritsen, K., Dahl, K., & Tougard, J. (2013). Re-established stony reef attracts harbour porpoises Phocoena phocoena. *Marine Ecology Progress Series,* 481, pp.239-248.

Milne, M.J., Kearins, K. & Walton, S. (2006). Creating adventures in wonderland - the journey metaphor & environmental sustainability. *Organization*, 13(6), pp.801-839.

Mirvis, P. & Googins, B. (2006). Stages of corporate citizenship: a developmental framework. *California Management Review,* 48(2), 104–126.

Mittendorff, K., Geijsel, F., Hoeve, A., de Laat, M. & Nieuwenhuis, L. (2006). Communities of practice as stimulating forces for collective learning. *Journal of Workplace Learning,* 18(5), pp.298-312.

Monier, V., Hestin, M, Cavé, J., Laureysens, I., Watkins, E., Reisinger, H., Porsch, L. (2014). *Development of Guidance on Extended Producer Responsibility (EPR).* European Commission – DG Environment.

Morsing, M. & Schultz, M. (2006). Corporate social responsibility communication: stakeholder information, response and involvement strategies. *Business Ethics: A European Review , 15*(4), pp.323-338.

Mortimer, C. (2010). *Literature review of enablers and barriers to adoption of life cycle management.* Landcare Research New Zealand Ltd.

Mukherjee, A., Kamarulzaman, N.H., Vijayan, G. & Vaiappuri, S.K.N. (2016). Sustainability: a comprehensive literature. In B., Christiansen (Eds.), *Handbook of Research on Global Supply Chain Management*, pp.248-268. Hershey: IGI Global.

Murillo, E. (2011). Communities of practice in the business and organization studies literature. *Information Research,* 16(1).

Murillo-Luna, J.L., Garcés-Ayerbe, C. & Pilar, R.-T. (2011). Barriers to the adoption of proactive environmental strategies. *Journal of Cleaner Production*, 19, pp.1417–1425.

Musgrove, P. (2010). *Wind Power, 1st ed.* Cambridge: Cambridge University Press.

Myrdal, C.G. (2010). Integrating environmental considerations in product development processes - based on a case study - research at the Danish pump manufacturer Grundfos (Doctoral dissertation). Aalborg University, Department of Development and Planning.

National Wind. (2010). *Wind turbine interactions with birds, bats and their habitats: A summary of research results and priority questions.*

Navigant Research (2015). *World Wind Energy Market Update 2015.* BTM Consult.

next47 (2016). *Fact sheet for innovation fields.* https://www.siemens.com/content/dam/internet/siemens-com/innovation/innovation/pdfs/next47-fact-sheet-innovationsfelder-overview-e.pdf.

next47 (2017). *Welcome to business as unusual*. https://www.next47.com/about-us/.

Nidumolu, R., Prahalad, C.K. & Rangaswami, M.R. (2009). Why sustainability is now the key of innovation. *Harvard Business Review,* 87, pp.57–64.

Noftke, S.E. & Stevenson, R.B. (1995). *Educational Action Research: Becoming Particularly Critical.* New York: Teachers College Press.

Norgaard, R. (1994). The Co-evolution of Economic and Environmental Systems and the Emergence of Unsustainability. In R., England (Eds.), *Evolutionary Concepts in Contemporary Economics*. Michigan: University of Michigan Press.

Novak, V.M. (2014). Design management of sustainability values: a learning organization perspective. *Architectural Engineering and Design Management*, 10(3-4), pp.218-232.

NRC (2007). *Prospective Evaluation of Applied Energy Research and Development at DOE (Phase Two).* Washington DC: National Research Center (NRC).

Öberg, C., Huge-Brodin, M. & Björklund, M. (2012). Applying a network level in environmental impact assessment. *Journal of Business Research,* 65, pp.247-255.

O'Donoghue, T. & Punch K. (2003). *Qualitative Educational Research in Action: Doing and Reflecting.* Abingdon-on-Thames: Routledge.

OECD (2001). *Extended Producer Responsibility: A Guidance Manual for Governments.* Paris: OECD.

OECD (2012). *An Emerging Middle Class.* Paris: OECD.

OECD (2013). *Water security for better lives.* Paris: OECD.

OECD & European Union (2005). *Oslo manual: guidelines for collecting and interpreting innovation data, 3rd ed.* Paris: OECD Publishing.

O'Hare, J.A. (2010). Eco-innovation tools for the early stages: an industry-based investigation of tool customization and introduction (Doctoral dissertation). University of Bath.

Økland, A. (2015). Gap analysis for incorporating sustainability in project management. *Procedia Computer Science,* 64, pp.103-109.

Olesen, J. (1992). Concurrent development in manufacturing – based upon dispositional mechanisms (Doctoral dissertation). Technical University of Denmark.

Olesen, M. (2014). Making light rail motilities (Doctoral dissertation). Aalborg University, Department of Development and Planning.

Olson, E. (2013). It's not easy being green: the effects of attribute tradeoffs on green product reference and choice. *Journal of the Academy of Marketing Science,* 41, pp.171-184.

Ørngreen, R. (2015). Reflections on design-based research. IN Online education and competence development projects. *IFIP International Federation for Information Processing 2015 J. Abdelnour-Nocera et al. (Eds.): HWID 2015, IFIP AICT 468,* pp.20–38.

O'Rourke, D. (2014). The science of sustainable supply chains. *Science,* 344(6188), pp.1124-1127.

Orr, J.E. (1990). Sharing knowledge, celebrating identity: community memory in a service culture. In R., Middleton & D., Edwards (Eds.), *Collective Remembering: Memory in Society*, pp.169-189. London: SAGE Publications.

Orsato, R.J. & Wells, P. (2007). The automobile industry & sustainability. *Journal of Cleaner Production*, 15, pp.989–993.

Ortegon, K., Nies, L.F. & Sutherland, J.W. (2013). Preparing for end of service life of wind turbines. *Journal of Cleaner Production*, 39, pp.191–199.

O'Shea, T., Golden, J. & Olander, L. (2013). Sustainability and earth resources: life-cycle assessment modelling. *Business Strategy and the Environment, 22*(7), pp.429-441.

Oxford Dictionaries (2015). Participation.

Papanek, V. (1971). *Design for the Real World: Human Ecology and Social Change*. New York: Pantheon Books.

Papista, E. & Krystallis, A. (2013). Investigating the types of value and cost of green brands: proposition of a conceptual framework. *Journal of Business Ethics,* 115(1), pp.74-92.

Park, P. (2006). Knowledge and participatory research. In B., Reason, H., Bradbury (Eds.), *The Handbook of Action Research. Concise Paperback Edition,* pp.83-93. Thousand Oaks: SAGE Publications.

Pasmore, W. (2006). Action research in the workplace: the socio-technical perspective. *The Handbook of Action Research. Concise Paperback Edition,* pp.38-48. Thousand Oaks: SAGE Publications.

Pasmore, W. & Fagans, M.R. (1992). Participation, individual development, and organizational change: a review and synthesis. *Journal of Management,* 18(2), pp.375-397.

Pasqualetti, M. J., Righter, R., & Gipe, P. (2004). History of Wind Energy. In C., Cleveland (Eds.), *Encyclopedia of Energy,* pp. 419-433. Amsterdam: Elsevier Science.

Patala, S., Jalkala, A., Keränen, J., Väisänen, S., Tuominen, V. & Soukka, R. (2016). Sustainable value propositions: framework and implications for technology suppliers. *Industrial Marketing Management, 59*, pp.144-156.

Pavel, C.C., Lacal-Arántegui, R. Marmier, A., Schüler, D., Tzimas, E., Buchert, M., Jenseit, W., Blagoeva, D. (2017). Substitution strategies for reducing the use of rare earths in wind turbines. *Resources Policy*, 52, pp.349-357.

Peirce, C.S. (1934). *Collected papers of Charles Sanders Peirce Volume V Pragmatism and Pragmatism and Volume VI Scientific Metaphysics.* Cambridge: University Press.

Perry, N., Bernard, A., Laroche, F. & Pompidou, S. (2012). Improving design for recycling - application to composites. *CIRP Annals - Manufacturing Technology,* 61, pp.151-154.

Pfitzner, R. & Lutz, M. (2015). Siemens: managing sustainability along the value chain. In M., D'heur (Eds.), *Sustainable Value Chain Management,* pp.207-225. Munich: Springer Publishing.

Phillips, L. (2009). Analysing the dialogic turn in the communication of research-based knowledge: an exploration of the tensions in collaborative research . *Public Understanding of Science,* 20(1), pp.1–21.

Pickering, S. (2006). Recycling technologies for thermoset composite materials - current status. *Composites Part A: Applied Science and Manufacturing,* pp.1206-1215.

Pigosso, D.C.A., McAloone, T.C. & Rozenfeld, H. (2015). Characterization of the state-of-the-art and identification of main trends for ecodesign tools and methods: classifying three decades of research and implementation. *Journal of Indian Inst. Sci.,* 94(4), pp.405-427.

Pigosso, D.C.A., Rozenfeld, H. & McAloone, T.C. (2013). Ecodesign maturity model: a management framework to support ecodesign implementation into manufacturing companies. *Journal of Cleaner Production*, 59(15), pp.160–173.

Pingeot, L. (2014). Scrutinizing the Corporate Role in the Post-2015. In Development Agenda in Worldwatch Institute. State of the world 2014. Governing for Sustainability.

Plouffe, S., Lanoie, P., Berneman, C. & Vernier, M.F. (2011). Economic benefits tied to ecodesign. *Journal of Cleaner Production*, 19(6-7), pp.573–579.

Polonsky, M.J. & Ottman, J.A. (1998). Exploratory examination of whether marketers include stakeholders in the green new product development process. *Journal of Cleaner Production*, 6, pp.269–275.

Porter, M. & Kramer, M. (2006). Strategy and society: the link between competitive advantage. *Harvard Business Review,* 84(12), pp.78-92.

Porter, M. & Kramer, M. (2011). Creating Shared Value. *Harvard Business Review,* 89(1/2), pp.62-77.

Porter, M. & Reinhardt, F. (2007). A strategic approach to climate change. *Harvard Business Review,* 10, pp.22-26.

Post, J.E. & Altman, B.W. (1994). Managing the environmental change process: barriers and opportunities. *Journal of Organizational Change Management,* 7(4), pp.64-81.

Poumadére, M., Bertoldo, R., & Samadi, J. (2011). Public perceptions and governance of controversial technologies to tackle climate change: nuclear power, carbon capture and storage, wind and geo-engineering. *Wiley interdisciplinary reviews,* 2(5), pp.712-727.

Prasad, P. & Elmes, M. (2005). In the name of the practical: unearthing the hegemony of pragmatics in the discourse of environmental management. *Journal of Management Studies,* 42(4), pp.845-867.

Prendeville, S.M., O'Connor, F., Bocken, N.M.P. & Bakker, C. (2017). Uncovering ecodesign dilemmas: a path to business model innovation. *Journal of Cleaner Production*, 143, pp.1327-1339.

PWC (2011). *Technology Forecast: Building sustainable companies. Issue 4* http://www.pwc.com/us/en/technology-forecast/2011/issue4/features/feature-sustainability-as-normal-business.html.

PwC (2014). *Five megatrends and possible implications, director's edition* http://www.pwc.com/us/en/corporate-governance/publications/cbg-megatrends-directors.html.

Quella, F. (2001). Environmentally compatible product design - the business strategy of Siemens. *Environmentally Conscious Design and Inverse Manufacturing, 2001. Proceedings EcoDesign 2001: Second International Symposium on, Tokyo, 2001,* pp.49-53.

Quist, J. & Tukker, A. (2013). Knowledge collaboration and learning for sustainable innovation and consumption: introduction to the ERSCP portion of this special volume. *Journal of Cleaner Production,* 48, pp.167–175.

Raadal, H., Vold, B., Myhr, A., & Nygaard, T. (2014). GHG emissions and energy performance of offshore wind power. *Renewable Energy,* 66, pp.314-324.

Ramberg, R. (2002). Rorty and the Instrument of Philosophy. In Peters & P., Ghiraldelli (Eds), *Richard Rorty: Philosophy, Culture and Education Rowman*, pp.35-45.Boulder: Littlefield, Boulder.

Ramirez, E., Gonzalez, R. & Moreira, G. (2014). Barriers and bridges to the adoption of environmentally-sustainable offerings. *Industrial Marketing Management, 43*(1), pp.16-24.

Ramirez-Tejeda, K., Turcotte, D. & Pike, S. (2017). Unsustainable wind turbine blade disposal practices in the United States: A case for policy intervention and technological intervention. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy,* 26(4), pp.581-598.

Reason, P. & Bradbury, H. (2006). Introduction: Inquiry and Participation in search of a world worth of human aspiration. In B., Reason, H., Bradbury (Eds.), *The Handbook of Action Research, Concise Paperback Edition,* pp.1-14. Thousand Oaks: SAGE Publications.

Recharge News (2015, March 27). Vestas tops 2014 turbine supplier ranking - BTM Navigant. *Recharge News*. http://www.rechargenews.com/wind/1395726/vestas-tops-2014-turbine-supplier-ranking-btm-navigant.

Reijnders, L. (1998). The factor X debate: setting targets for eco-efficiency. *Journal of Industrial Ecology*, 2(1), pp.13-22.

Remmen, A. (2001). Greening of Danish Industry: changes in concepts and policies. *Technology Analysis & Strategic Management*, 13(1), pp.53-69.

Remmen, A. (2006). Integrated product policy in Denmark. New Patterns of Environmental Governance? In F.S.D., Rubik (Eds.), *Governance of Integrated Product Policy*. Sheffield: Greenleaf Publishing.

Remmen, A. & Lorentzen, B. (2000). Employee participation and cleaner technology: learning processes in environmental teams. *Journal of Cleaner Production*, 8(5), pp.365-373.

Remmen, A. & Münster M. (2003). An introduction to life-cycle thinking and management. *Environmental News,* no.68. Danish Ministry of the Environment. Copenhagen.

Reyes, T., Millet, D. & Brissaud, D. (2006). Study of ecodesign integration process in French companies. *13th CIRP International Conference of Life Cycle Engineering,* 13, pp.267–274.

Richter, M. (2012). Utilities' business models for renewable energy: a review. *Renewable and Sustainable Energy Reviews*, 16, pp.2483-2493.

Rittel, H. & Webber, M. (1973). Dilemmas in a general theory of planning. *Policy Sciences* 4(2), pp.155-169.

Robèrt, K.H., Schmidt-Bleek, B., Aloisi de Larderelc, J., Basile, G., Jansen, J.L., Kuehr, R., Price Thomas, P., Suzuki, M., Hawken, P. & Wackernagel, M. (2002). Strategic sustainable development - selection, design and synergies of applied tools. *Journal of Cleaner Production,* 10(3), pp.197-214.

Rocha, C. & Brezet, H. (1999). Product-oriented environmental management systems: a case study. *Journal of Sustainable Product Design*. pp.30-42.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F., Lambin, E., . . . Hu, T. (2009). Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society,* 14(2), pp.32.

Rogner, H., Barthel, F., Cabrera, M., Faaij, A., Giroux, M., Hall, D., . . . Taylor, M. (2000). Energy resources. In United Nations (Eds.), *World Energy Assessment. Energy and the Challenge of Sustainability,* pp. 30-37. New York: World Energy Council.

Rohrmus, D., Mose, C., Holst, J.C., Muller, K., Schedlbauer, M., Raschke, U. & Weinert, N. (2011). Sustainable Manufacturing at Siemens AG. In G. Seliger et al. (Eds.), *Advances in Sustainable Manufacturing: Proceedings of the 8th Global Conference 79 on Sustainable Manufacturing.* Berlin: Springer Publishing.

Rokka, J. & Uusitalo, L. (2008). Preference for green packaging in consumer product choices - Do consumers care? *International Journal of Consumer Studies,* 32, pp.516-525.

Romme, A.G. (2003). Making a difference: organization as design. *Organization Science.*14, pp.558-573.

Rosenau, M.D., Griffin, A., Castellion, G.A. & Anschuetz, N.F. (1996). The PDMA Handbook of New Product Development, 1st ed. New York: John Wiley & Sons Inc.

Rossi, M., Germani, M. & Zamagni, A. (2016). Review of ecodesign methods and tools. Barriers and strategies for an effective implementation in industrial companies. *Journal of Cleaner Production,* 129(1), pp.361-373.

Roundtable for Product Social Metrics (2014). *Handbook for Product Social Impact Assessment.*

Saidur, R., Saidur, R., Rahim, N., Islam, M., & Solangi, K. (2011). Environmental impact of wind energy. *Renewable & sustainable energy reviews,* 15(5), pp.2423-2430.

Saling, P. (2015). Sustainability improvements and life cycle approaches in industry partnerships. In G., Sonnemann & M., Margni (Eds.), *Life Cycle Management,* pp.117-127. New York: Springer Publishing.

Saling, P., Kicherer, A., Dittrich-Krämer, B., Wittlinger, R., Zombik, W., Schmidt, I., Schrott, W., and Schmidt, S., (2002). Eco-efficiency analysis by BASF: the method. *International Journal of Life Cycle Assessment*, 7(4), pp.203-218.

Salzmann, O., Ionescu-Sommers, A.M. & Steger, U. (2005). The business case for corporate sustainability: literature review and research options. *European Management Journal,* 23(1), pp.27-36.

Sánchez, M.A. (2015). Integrating sustainability issues into project management. *Journal of Cleaner Production,* 96, pp.319-330.

Saunders, M. (2011). The management researcher as practitioner. In C., Cassell & W.J., Lee (Eds.), *Challenges and Controversies in Management Research,* pp.243-256. London: Taylor and Francis.

Saunders, M., Lewis, P. & Thornhill, A. (2009). *Research Methods for Business Students, 5th ed.* Essex: Pearson Education Limited.

Saunders, M. & Tosey, P. (2012). The layers of research design. Academia. https://www.academia.edu/4107831/The_Layers_of_Research_Design.

Saxe, J.G. (1987). The Blind Men and the Elephant. https://en.wikisource.org/wiki/The_poems_of_John_Godfrey_Saxe/The_Blind_Men_and_the_Elephant.

Schaefer, A. & Harvey, B. (2000). Agents of change in corporate "greening". Case studies in water and electricity utilities. In S., Fineman, (Eds.), The Business of Greening. London: Routledge.

Schein, E.H. (2004). *Organizational Culture and Leadership, 3rd ed.* New York: Jossey-Bass.

Schleisner, L. (2000). Life cycle assessment of a wind farm and related externalities. *Renewable Energy,* 20(3), pp.279-288.

Schmidheiny, S. (1992). *Changing Course: A Global Business Perspective on Development and the Environment*. Cambridge: The MIT Press.

Schmidt, K. & Remmen, A. (2013). Images of environment and management practice: conflicting priorities or platform for organizational learning? *Paper presented at ERSCP-EMSU 2013, Istanbul, Turkey.*

Schmidt, W. (2003). Life cycle costing as part of design for environment. Environmental business cases. *International Journal of Life Cycle Assessment,* 8(3), pp.167-174.

Schmidt-Bleek, F. (2008). Factor 10 Institute. Webpage. http://www.factor10-institute.org/index.html.

Schweitzer, E. & Aurich, J. (2010). Continuous improvement of industrial product-service systems. *CIRP Journal of Manufacturing Science and Technology, 3*(2), pp.158-164.

Scott, J. (1990). *A Matter Of Record.* Cambridge: Polity Press.

Seaman, W. (2007). Artificial habitats and the restoration of degraded marine ecosystems and fisheries. *Hydrobiologia,* 580, pp.143-155.

Sein, M.K., Henfridsson, O., Purao, S., Rossi, M. & Lindgren, R. (2011) Action design research. *MIS Quarterly*, 35(1), pp.37-56.

Senge, P.M. (1990). *The Fifth Discipline: The Art and Practice of the Learning Organization.* New York: Doubleday.

Shani, A.B. & Pasmore, W.A. (1985). Organization inquiry: towards a new model of the action research process. In D.D., Warrick (Eds.), *Contemporary Organization Development: Current Thinking and Applications,* pp.438-448, Glenview: Scott, Foresman.

Sharma, A., Lyer, G., Mehrotra, A. & Krishnan, R. (2010). Sustainability and business-to-business marketing: a framework and implications. *Industrial Marketing Management,* 39, pp.330-333.

Shen, L., Zeng, S. & Tam, V. (2017) Special edition: Social responsibilities for the management of megaprojects. *International Journal of Project Management,* 35(7), pp.1336-1337.

Short, T., Lee-Mortimer, A., Luttropp, C. & Johansson, G. (2012). Manufacturing, sustainability, ecodesign and risk: lessons learned from a study of Swedish and English companies*. Journal of Cleaner Production*, 37, pp.342–352.

Siemens (2004, October 20). *Siemens overtager Bonus Energy A/S i Danmark og går ind i markedet for vindenerg*. Press release. http://w3.siemens.dk/home/dk/dk/cc/presse/meddelelser/arkiv/pages/overtager_bonus_energy_as_danmark_gaar_ind_markedet_for_vindenergi.aspx.

Siemens (2009a, December 23). *DONG Energy og Siemens indgår ny leveringsaftale om offshore vindmøller.* Press release. http://w3.siemens.dk/home/dk/dk/cc/presse/meddelelser/arkiv/Pages/dong_nergy_indgaar_leveringsaftale_om_offshore_vindmoeller.aspx.

Siemens (2009b, June 10). Hywind: Siemens and StatoilHydro install first floating wind *turbine*. Press release. http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2009/renewable_energy/ere200906064.htm.

Siemens (2010a, June 29). *Siemens to become equity partner in offshore wind park installation specialist A2SEA*. Press release. https://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2010/renewable_energy/ere201006097.htm&content[]=ER&content[]=EW&content[]=WP.

Siemens (2010b, May 11). *Environmental solutions increase competitiveness in mining and steel industries*. Press release. https://www.siemens.com/press/en/presspicture/?press=/en/presspicture/2010/industry_solutions/iis201005406-01.htm.

Siemens (2011, November 29). *Siemens lancerer ny 6-MW direct drive offshore vindmølle.* Press release. http://w3.siemens.dk/home/dk/dk/cc/presse/meddelelser/arkiv/Pages/6-MW-direct-drive-vindmoelle.aspx.

Siemens (2012a, May 22). *Siemens sætter ny rekord for døgnproduktion fra vindmølle.* Press release. http://w3.siemens.dk/home/dk/dk/cc/presse/meddelelser/2012/pages/2012-05-22-ny-rekord.aspx.

Siemens (2012b). *The Siemens Environmental Portfolio. Examples of Sustainable Technologies.* Munich: Siemens.

Siemens (2014a). *Strategic overview*. Webpage. https://www.siemens.com/about/en/strategic-overview.htm.

Siemens (2014b). Reports and Rankings. Rankings. Website. http://www.siemens.com/about/sustainability/en/sustainability/reporting/rankings.htm.

Siemens (2014c, November 30). *Wind 2020. The Wind Power and Renewables Division's strategy*. SiemensWorld. https://newscenter.siemens.com/siemens-news/index.php?webcode=50014947&lang=en&rwlogin=1.

Siemens (2015a). *Siemens Annual report 2014.* Munich: Siemens.

Siemens (2015b, May 19). *Siemens installs prototype of its 7-megawatt offshore wind turbine.* Press release. http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2015/windpower-renewables/pr2015050226wpen.htm&content[]=WP.

Siemens (2015c, November 17). *Siemens reduces transport costs for offshore wind turbines by up to 20 percent*. Press release. https://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2015/windpower-renewables/pr2015110088wpen.htm.

Siemens (2015d) *Smooth service on the rough seas*. Webpage. https://www.siemens.com/stories/cc/en/smooth-service-on-the-rough-seas/

Siemens (2016a, May 06). *A campus for hammering out innovation.* SiemensWorld. https://newscenter.siemens.com/siemens-news/index.php?webcode=50047463&rwlogin=1.

Siemens (2016b, January 26). *Earnings release and financial results Q1 FY 2016: Strong start into the fiscal year – earnings outlook raised.* Press release. www.siemens.com/press/PR2016010140COEN.

Siemens (2016c). *Quiet as an owl's flight.* Siemens Wind Power. https://newscenter.siemens.com/siemens-news/index.php?webcode=50051132&lang=en&rwlogin=1.

Siemens (2016d). SCoE: The true cost of offshore wind power. Webpage. https://www.siemens.com/customer-magazine/en/home/energy/renewable-energy/scoe-the-true-cost-of-offshore-wind-power.html.

Siemens (2016e) *Sustainability Information 2015.* As addendum to the Siemens Annual Report. Munich: Siemens.

Siemens (2017a). *Siemens research cooperation with universities: Strategic university relations strengthening Siemens' ingenuity*. Munich: Orazbayeva, B.

Siemens (2017b). *Siemens History*. Webpage. http://www.siemens.com/history/en/.

Siemens (2017c). *Siemens Sustainability Information 2016.* As addendum to the Siemens Annual Report. Munich: Siemens.

Siemens (2017d). *Company presentation 2017.* Webpage. https://www.siemens.com/investor/en/company_overview.htm.

Siemens (2017e). *From inventiveness to Ingenuity for life*. Webpage. https://www.siemens.com/global/en/home/company/topic-areas/ingenuity-for-life.html.

Siemens (2017f). *Robust and low-weight: all-rounder blades.* Webpage. https://www.siemens.com/global/en/home/markets/wind/turbines-and-services/technology/blades.html.

Siemens (2017g) *World Environmental Day 2017. Connecting People to Nature*. SiemensWorld. https://newscenter.siemens.com/siemens-news/index.php?webcode=50062609&lang=en&rwlogin=1.

Siemens (2017h). *Internal guidelines*. Webpage. Retrieved from: https://www.siemens.com/about/sustainability/en/sustainability-at-siemens/internal-guidelines.php.

Siemens (2017i) *Further information on stakeholder dialogue at Siemens.* PowerPoint slides. https://www.siemens.com/content/dam/internet/siemens-com/global/company/sustainability/downloads/stakeholder-engagement-siemens.pdf.

Siemens (2017j) *Carbon-neutral operations by 2030*. Webpage. https://www.siemens.com/global/en/home/company/sustainability/decarbonization.html#Siemensisgoingcarbonneutral.

Siemens (2017k) *Siemens' Environmental Portfolio – our decarbonisation driver*. Webpage. https://www.siemens.com/global/en/home/company/sustainability/decarbonization.html#SiemensEnvironmentalPortfolio.

Siemens (2017l) *Ratings and rankings - outstanding commitment*. Webpage. https://www.siemens.com/global/en/home/company/sustainability.html#Ratingsandrankings.

Siemens (2017m) *Why contributing to sustainable development matters*. Webpage. https://www.siemens.com/global/en/home/company/sustainability/business-to-society.html

Siemens Gamesa Renewable Energy (2017). *Key figures of the combined business.* Webpage. http://www.gamesacorp.com/gamesa/en/siemensgamesa.html.

Siemens Wind Power (2014). *What is the real cost of offshore wind. A macro-economic viewpoint.* Hamburg: Siemens.

Siemens Wind Power (2015). *Environmental Product Declarations.* Brande: Siemens Wind Power. https://www.siemens.com/global/en/home/markets/wind/facts/environment.html.

Siemens Wind Power (2016a). *Company Presentation, FY2016. Siemens Wind Power and Renewables Division.* Brande:Siemens Wind Power

Siemens Wind Power (2016b). Product Development Processs (PDP) Handbook (Version4.0). Internal document.

Siemens Wind Power (2016c). *Company Presentation.* Internal document.

Siemens Wind Power (2017a). *A clean energy solution – from cradle to grave. Offshore wind power plant employing SWT-7.0-154.* Brande: Siemens Wind Power. https://www.siemens.com/global/en/home/markets/wind/facts/environment.html.

Siemens Wind Power (2017b). *The price of electricity. Wind power: redefining the cost debate*. Webpage. https://www.siemens.com/global/en/home/markets/wind/facts/cost-of-electricity.html.

Silva, A., Rosano, M., Stocker, L. & Gorissen, L. (2017). From waste to sustainable materials management: Three case studies of the transition journey. *Waste Management,* 61, pp.547-557.

Skelton, K., Huulgaard, R.D. & Schmidt, K. (2016). Understanding ecodesign through a communities of practice perspective. *International Journal of Environmental Technology and Management,* 19(1), pp.40-58.

Slabbert, Y. & Barker, R. (2014). Towards a new model to describe the organisation–stakeholder relationship-building process: a strategic corporate communication perspective. *South African Journal for Communication Theory and Research,* 40(1), pp.69-94.

Song, Y.S., Youn, J.R. & Gutowski, T.G. (2009). Life cycle energy analysis of fiber-reinforced composites. *Composites: Part A,* 40, pp.1257-1265.

Sonnemann, G. & Valdivia, S. (2014). The UNEP/SETAC Life Cycle Initiative. In W., Klopffer (Eds.), *Background and Future Prospects in Life Cycle Assessment.* London: Springer Publishing.

Sovacool, B. & Enevoldsen, P. (2015). One style to build them all: corporate culture and innovation in the offshore wind industry. *Energy Policy,* 86, pp.402-415.

Spangenberg, J.H. (2001). Sustainable Development. From Catchwords to benchmarks and operational concepts. In M., Charter & U. Tischner (Eds.), *Sustainable Solutions: Developing Products and Services for the Future.* Sheffield: Greenleaf Publishing.

Spangenberg, J.H., Fuad-Luke, A. & Blincoe, K. (2010). Design for Sustainability (DfS): the interface of sustainable production and consumption. *Journal of Cleaner Production*, 18(15) pp.1483-1491.

Staff, I. (2015, March 9). Siemens world no1 OEM in 2014, says Make Consulting. *Windpower Monthly*. http://www.windpowermonthly.com/article/1337324/siemens-world-no1-oem-2014-says-consulting.

Stage-Gate® Innovation Consultants (2015). Innovation Process. Stage-Gate® Idea-to-Launch Model. http://www.stage-gate.com/resources_stage-gate.php.

Star, S L. & Griesemer, J.R. (1989). Institutional ecology, translations and boundary objects: amateurs and professionals in Berkeleys museum of vertebrate zoology. *Social Studies of Science*, 193, pp.387-420.

Stevels A. (2009). *Adventures in EcoDesign of Electronic Products: 1993-2007*. Delft: VSSD.

Stevels, A., (2016). *The Reverse Perspective: Fifteen Years of EcoDesgin at Philips Consumer Electronics (1993-2008).* Self-published.

Stewart, R. (2012). Wind turbine blade production - new products keep pace as scale increases. *Reinforced Plastics,* 56(1), pp.18-25.

Stikker, A. (1997). Putting systems into practice. In P., Bansal & E., Howard (Eds.), *The Oxford Handbook of Business and the Natural Environment.* Oxford: Butterworth-Heinemann.

Stone, L.J. (2006a). Limitations of cleaner production programmes as organisational change agents. I. Achieving commitment and on-going improvement. *Journal of Cleaner Production*, 4, pp.1-14.

Stone, L.J. (2006b). Limitations of cleaner production programmes as organisational change agents. II. Leadership, support, communication, involvement and programme design. *Journal of Cleaner Production*, 4, pp.15–30.

Stram, B. (2016). Key challenges to expanding renewable energy. *Energy Policy,* 96, pp.728-734.

Sukhdev, P. (2013). Transforming the corporation into a driver for sustainability. In Worldwatch Institute (Eds.), State of the World 2013. Is Sustainability Possible? Washington: Island Press.

Sulkowski, A., Edwards, M. & Freeman, R. (2017). Shake your stakeholder: firms leading engagement to co-create sustainable value. *Organization & Environment*, 1-19.

Swamy, N.K. (2012). Application of LCA to the wind turbine industry: a cradle-to-gate study of a wind blade (Master's dissertation). Aalborg University, Department of Development and Planning.

Swan, J., Bresnen, M., Newell, S. & Roberson, M. (2007). The object of knowledge: the role of objects in biomedical innovation. *Human Relations,* 60(12), pp.1809-1837

Swarr, T. (2011). A capability framework for managing social and environmental concerns. *International Journal of Life Cycle Assessment,* 16, pp.593–595.

Tecnológico, Asociación Eólica Empresarial. Observatorio (2016). Innovación en el desarrollo de palas.

Tellioglu, H., Wagner, I. & Lainer, R. (1998). Open design methodologies. exploring architectural practice for systems design*, in: Proceedings of the Participatory Design Conference ``Broadening Participation", November 12-14. Seattle, WA, USA, pp.19–28.*

Thabrew, L., Wiek, A. & Ries, R. (2009). Environmental decision making in multi-stakeholder contexts: applicability of life cycle thinking in development planning and implementation. *Journal of Cleaner Production,* 17, pp.67–76.

The Design-Based Research Collective (2003). Design-based research: an emerging paradigm for educational inquiry. *Educational Researcher,* 32(1), pp.5–8.

The University of Sheffield (2016). Magnetic attraction: towards a low carbon future with Rolls-Royce, Siemens and Nissan. https://www.sheffield.ac.uk/research/impact/stories/low-carbon-rolls-royce-siemens-nissan-1.567945.

Thøgersen, J. & Schrader, U. (2012). From knowledge to action - new paths towards sustainable consumption. *Journal Consumer Policy,* 35, pp.1-5.

Tilt, C.A. (2002). Frameworks for assessing business response to the environment: a critical review. *Journal of Accounting and Finance*, 1 pp.29-41.

Tischner, U., Schmincke, E., Rubik, F. & Prösler, M. (2000). *How to Do Ecodesign?: A Guide for Environmentally and Economically Sound Design.* German Federal Environmental Agency.

Tosey, P., Visser, M. & Saunders, M.N.K. (2011). The origins and conceptualizations of 'triple-loop' learning: a critical review. *Management Learning,* 43(3), pp.291-307.

Trist, E. (1979). New directions of hope: recent innovations interconnecting organizational, industrial, community and personal development. *Regional Studies*, 13, pp.439-51.

TSC (2017). Sustainability consortium members. https://www.sustainabilityconsortium.org/members/.

Tyl, B., Lizarralde, I. & Allais, R. (2015). Local value creation and eco-design: a new paradigm. *CIRP Annals,* 30, pp.155-160.

UCS (Union of Concerned Scientists) (1993). World Scientists' Warning to Humanity. Cambridge: Union of Concerned Scientists.

UN (United Nations) (1992). Agenda 21. United Nations Conference on Environment & Development Rio de Janerio, Brazil, 3 to 14 June 1992 https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf.

UN (United Nations) (2017). *Sustainable Development Goal 17,* New York: United Nations.

UNEP (United Nations Environmental Program) (1997). *Ecodesign: A Promising Approach to Sustainable Production and Consumption.* Brezet, H., van Hemel, C.

UNEP (United Nations Environmental Program) (2007). *Life Cycle Management. A Business Guide to Sustainability.* Remmen, A., Jensen, A.A., Frydendal, J.

UNEP (United Nations Environmental Program) (2010a). *ABC of SCP – Clarifying Concepts on Sustainable Consumption and Production.* Arden-Clark, C., Farah, A.Z.

UNEP (United Nations Environmental Program) (2010b). *Assessing the Environmental Impacts of Consumption and Production: Priority Products and Materials, A Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management.* Hertwich, E., van der Voet, E., Suh, S., Tukker, A., Huijbregts M., Kazmierczyk, P., Lenzen, M., McNeely, J., Moriguchi, Y.

UNEP/SETAC (United Nations Environment Program / Society of Environmental Toxicology and Chemistry) (2009). *Life Cycle Management: How Business Uses it to Decrease Footprint, Create Opportunities and Make Value Chains More Sustainable.*

UNGC (United Nations Global Compact) (2015). *IMPACT: Transforming Business, Changing the World - The United Nations Global Compact.* DNV GL; United Nations Global Compact.

Vakkayil, J.D. (2014). Boundary objects in boundary-spanning. In J., Langan-Fox, & C.L., Cooper (Eds.), *Boundary-Spanning in Organizations. Network, Influence and Conflict*, pp.29-43. New York: Routledge.

van Aken, J.E. (2004). Management research based on the paradigm of the design sciences: The quest for field-tested and grounded technological rules. *Journal of Management Sciences*, 41, pp.219-246.

van Hemel, C. (1998). Ecodesign empirically explored. Design for environment in Dutch small and medium sized enterprises (Doctoral dissertation). Delft University of Technology.

van Hemel, C. & Cramer, J. (2002). Barriers and stimuli for ecodesign in SMEs. *Journal of Cleaner Production*, 10(5), pp.439–453.

Vattenfall (2014). *Electricity from Vattenfall's wind farms in the UK.* Vattenfall. http://www.environdec.com/en/Detail/epd517.

Vattenfall (2016). *Electricity from Vattenfall's Nordic wind farms.* Vattenfall. http://www.environdec.com/en/Detail/epd183.

Verhulst E. (2012). The human side of sustainable design implementation from the perspective of change management (Doctoral dissertation). Universiteit Antwerpen.

Verhulst E. & Boks C. (2012). Bringing about sustainable change in product development: theory versus practice. In J., Frick & B.T., Laugen (Eds.), *Advances in Production Management Systems. Value Networks: Innovation, Technologies, and Management*. APMS 2011. IFIP Advances in Information and Communication Technology, vol 384. Berlin: Springer Publishing.

Verhulst E., Boks C., Stranger M. & Masson H. (2007). The human side of ecodesign from the perspective of change management. In S., Takata & Y., Umeda (Eds.), *Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses.* pp.107-112. London: Springer Publishing.

Verhulst, E., Dewit, I. & Boks, C. (2012). Implementation of sustainable innovations and business models. In M., Wagner (Eds.), *Entrepreneurship, Innovation and Sustainability*. London: Greenleaf Publishing.

Veshagh, A., Marval, S. & Woolman, T. (2012). Making the business case for eco-design and sustainable manufacturing. In D.A., Dornfeld & B.S., Linke (Eds.), *Leveraging Technology for a Sustainable World*, pp.11-17. London: Springer Publishing.

Vestas (2006). *LCA of electricity delivered from an onshore power plant based on Vestas V82-1.65 MW turbines.* Aarhus: Vestas.

Vestas (2011a). *LCA of electricity production from a Vestas V112 turbine wind plant.* Aarhus: Vestas.

Vestas (2011b). *LCA of electricity production from a V90-2.0 MW gridstreamer wind plant.* Aarhus: Vestas.

Vestas (2014). *LCA of electricity production from an onshore V126-3.3 MW wind plant.* Aarhus: Vestas.

von Karczewski, J., & Zistl, S. (2017). Disrupting Communication: Innovation Communications in the Digital Age. In N., Pfeffermann & J., Gould (Eds.), *Strategy and Communication for Innovation. Integrative Perspectives on Innovation in the Digital Economy, 3rd ed.,* pp. 367-384. Dusseldorf: Springer Publishing.

von Weizsäcker, E., Lovins, A.B. & Lovins, L. (1997). Factor Four: Doubling Wealth, Halving Resource Use. London: Earthscan Publications Ltd.

Wagner, H., & Mathur, J. (2013). Life Cycle Assessment of a Wind Farm. In H., Wagner & J., Mathur (Eds.), *Introduction of Wind Energy Systems, Green Energy and Technology*. London: Springer Publishing.

Wainstein, M. & Bumpus, A. (2016). Business models as drivers of low carbon power system transition: a multi-level perspective. *Journal of Cleaner Production,* 126, pp.572-585.

Wang, F. & Hannafin, M.J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, 53(4), pp.5-23.

Warren, C., Lumsden, C., O'Dowd, S., & Birnie, R. (2005). 'Green on Green': Public perceptions of wind power in Scotland and Ireland. *Journal of Environmental Planning and Management,* 48(6), pp.853-875.

WCED (World Commission on Environment and Development) (1987). *Our Common Future: Report of the World Commission on Environment and Development.* UN Documents Gathering Body of Global Agreements. Oxford University Press.

Weick, K.E. (1995). *Sensemaking in Organizations*. London: SAGE Publications.

Weinzettel, J., Reenaas, M., Solli, C., & Hertwich, E. (2009). Life cycle assessment of a floating offshore wind turbine. *Renewable Energy,* 34, pp.742-747.

Welch, D. (2015). Sustainable production and consumption. In J.D., Wright (Eds.), *International Encyclopaedia of the Social & Behavioural Sciences, 2nd ed,,* Vol 23, pp.839–844. Oxford: Elsevier.

Wenger, E. (1998). *Communities of Practice: Learning, Meaning and Identity*. Cambridge: Cambridge University Press.

Wenger, E. (2000a). Communities of practice: learning as a social system*. Systems Thinker,* 9(5), pp.2-3.

Wenger, E. (2000b). communities of practice and social learning systems. *Organization*, 7(2), pp.225-246.

Wenger, E. (2004). Knowledge management as a doughnut: shaping your knowledge strategy through communities of practice. *Ivey Business Journal Online,* January/February.

Wenger, E. (2010). Communities of practice and social learning systems: the career of a concept. In C., Blackmore (Eds.), *Social Learning Systems and Communities of Practice*, pp.179-198. Boston: Harvard Business School Press.

Wenger, E., McDermott, R. & Snyder, W.M. (2002). Cultivating Communities of Practice. Boston: Harvard Business School Press.

Wenger, E. & Snyder, W.M. (2000). Communities of practice: the organizational frontier. *Harvard Business Review,* 78(1), pp.139-145.

Weston, D. (2016, January 8). London Array breaks offshore production record. *Windpower Offshore.* http://www.windpoweroffshore.com/article/1378756/london-array-breaks-offshore-production-record.

Weston, D. (2017, February 22). *Siemens-Gamesa merger to create a "big-four" of OEM.* Windpower Monthly. http://www.windpowermonthly.com/article/1425082/siemens-gamesa-merger-create-big-four-oems.

Weterings R., Kuijper, J. & Smeets, E., (1997). *81 options. Technology for sustainable development.* Report for the Ministry of Housing, Physical Planning and the Environment. NL.

Wieringa, R. & Morali, A. (2012). Technical action research as a validation method in information systems design science. *Proceedings DESRIST 2012, LNCS 7286,* Berlin: Springer Publishing.

Wilhelmsson, D., Öhman, M., Ståhl, H., & Shlesinger, Y. (1998). Artificial reefs and dive tourism in Eilat, Israel. *AMBIO,* 27, pp.764-766.

WindEurope (2015). *Wind in power. 2016 European statistics.*

Winkelbach, A. & Walter, A. (2015). Complex technological knowledge and value creation in science-to-industry technology transfer projects: the moderating effect of absorptive capacity. *Industrial Marketing Management,* 47, pp.98-108.

Wiser, R., Yang, Z., Hand, M., Hohmeyer, O., Infield, D., Jensen, H., . . . Zervos, A. (2011). Wind Energy. In O., Edenhofer, R., Pichs-Madruga, Y., Sokona, K., Seyboth, P., Matschoss, S., Kadner & T., Zwickel (Eds.), *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation,* pp. 535-608. Cambridge: Cambridge University Press.

Wolsink, M. (2007). Planning of renewables schemes: deliberative and fair decision-making on landscape issues instead of reproachful accusations of non-cooperation. *Energy Policy,* 35(5), pp.2692-2704.

Woodside, A. (2010). *Case Study Research: Theory, Methods and Practices.* Brantford: Emerald Group Publishing Ltd.

World Bank (1996). The World Bank Participation Sourcebook. Washington.

WPB (World Population Balance) (2016). World population balance. http://www.worldpopulationbalance.org/faq.

Yin, R.K. (2009). *Case Study Research - Design and Methods*. Thousand Oaks: SAGE Publications.

Yukl, G. (2008). How leaders influence organizational effectiveness. *Leadership Quarterly,* 19, pp.708–722.

Zahari, F. & Thurasamy, R. (2012). Linking green product innovation, technological and human resource capabilities: a conceptual model. *International conference on innovation, management and technology research (ICIMTR2012) Malaysia 21-22 May 2012. 978-1-4673-0654-6/12.*

Zeng, S.X., Ma, H.Y., Lin, H., Zeng, R.C. & Tam, V.W. (2015). Social responsibility of major infrastructure projects in China. *International Journal of Project Management,* 33(3), pp.537–548.

Zhang, H.C., Kuo, T.C. & Lu, H. (1997). Environmentally conscious design and manufacturing: a state-of-the-art survey. *Journal of Manufacturing Systems,* 16(5), pp.352-371.

Zutshi, A. & Sohal, A. (2004). A study of the environmental management system (EMS) adoption process within Australasian organisations - 2. Role of stakeholders. *Technovation,* 24, pp.371–386.

APPENDECES

APPENDIX A

INVESTIGATION OF THE PROSPECTIVE USE OF THE ECO-CARE-MATRIX

Investigation of the Prospective Use of the Eco-Care-Matrix – An Empirical Study

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Presentation track: RS-10. Life Cycle Sustainability Assessment

This session focuses both on development of life cycle sustainability assessment, for example through indicator development, as well as on case studies including not only the environmental dimension of sustainability but also the social and/or economic dimension.

Abstract:

A variety of different environmental assessment tools have been developed and used by companies over recent years in order to assess and communicate product related environmental impacts. One example is the Eco-Care-Matrix (ECM) which was developed by Siemens AG, using life cycle assessment (LCA) and life cycle cost (LCC) methodologies, in order to assess the environmental and economic effectiveness between two product, technology or system designs. It can be stated that from a methodological perspective, much attention and effort has been given to develop the ECM methodology but less attention has been given to its application and effectiveness from an organizational and user perspective.

A pilot project investigating the prospective application and use of the ECM in one of Siemens Divisions was recently conducted to assess this claim. Feedback was gathered from stakeholders of various functions throughout the product lifecycle management (PLM) through a set of workshops. The perceived usefulness of the ECM as an eco-tool for both internal and external purposes is presented and discussed. It remains too early to speculate if the ECM will be adopted as a routine eco-tool in this Division. However, insight is given regarding an eco-tools changing role over time and how adoption and routine use is very much connected to the learning processes within an organization.

Keywords: Eco-Care-Matrix (ECM), life cycle assessment (LCA), life cycle cost (LCC), application, adoption

1. Introduction

A variety of different eco-tools have been developed and used by companies over recent years in order to assess and communicate product related environmental impacts. One example is Siemens AG, where the role of Life Cycle Assessments (LCAs) and Life Cycle Costing (LCC) have become increasingly important.[12]

In 2004, Siemens AG developed the Eco-Care-Matrix (ECM). Utilizing a combination of LCA and LCC methodologies, the ECM graphically compares both the environmental impacts (vertical axis) and cost effectiveness (horizontal axis) of anything from a product to a complete industry technology or system solution, with those of a reference product, technology or system.[3]

Since 2009, the ECM has been extensively used by one of Siemens' Divisions, where it has been applied both internally in the Division's green product lifecycle management (PLM) and externally in the results of its Environmental Product Declarations (EPDs). For the Division, it has proved to be an effective tool for illustrating environmental impacts while also highlighting design improvements.[45]

However, as a multinational conglomerate working with a broad-ranging portfolio in various other Sectors and Divisions, Siemens AG recognized that the ECM had to be further refined and standardized for the other organizational units who were not currently using it. As a result, the Siemens AG Eco-Care-Matrix Pilot Application was initiated in late 2011, which sought to apply the eco-tool to different product contexts and adjust the methodology accordingly.

It can be stated that from a methodological perspective, much attention and effort has been given to develop the ECM methodology but less attention has been given to its application and effectiveness from an organizational perspective.

Siemens AG claims that the ECM can be adapted to the needs of its diverse group of Divisions without significant effort. Two central questions arise from this claim: (1) if the ECM has been available for so many years, why has it not been institutionalized in more than one Division? and (2) what organizational aspects are required to improve the ECMs likeliness of being accepted and routinely applied?

2. Framework and theoretical background

This section explains the methodology behind the ECM and its potential applications, in addition to the theoretical explanation of the adoption process.

2.1 Eco-Care-Matrix

In 2004 Siemens AG developed the Eco-Care-Matrix (ECM) in collaboration with the Technical University of Denmark (DTU). Based on a former approach from BASF[6], the ECM is a graphical representation that compares both the ecological (vertical axis) and economic (horizontal axis) effectiveness of anything from a product to a complete industry technology or system solution, with those of a reference product, technology or system. It utilizes a combination of Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) methodologies to make these comparisons. Figure 1 illustrates the ECM concept.

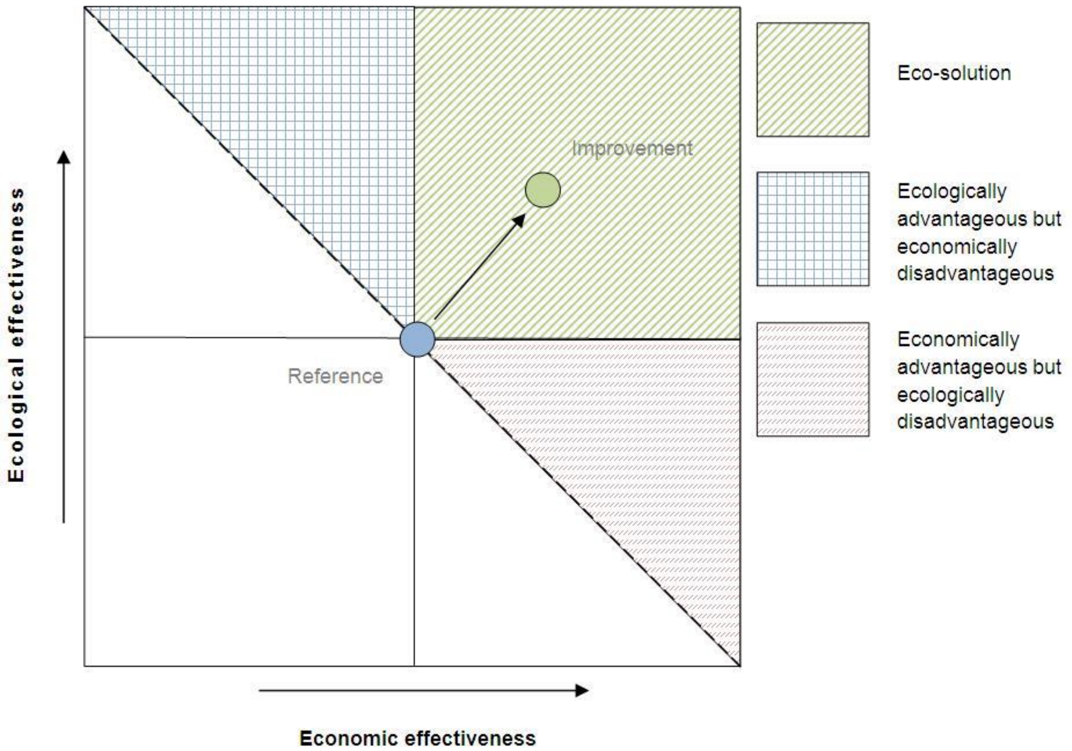

Figure 1. Eco-Care-Matrix (ECM)[78]

The reference dot in the center of the matrix represents an existing product[1] for comparative purposes. The corresponding dot represents the design successor. In order to be considered an overall improvement, the successor should be better in both eco-dimensions (ecological and economical) when plotted against the reference. Furthermore, the functional units of both dots must correspond to the same dimension.

In order to obtain information on the ecological effectiveness, four quantitative methods are possible[9]:

- CO2 screening
- Expanded global warming potential (GWP) screening
- Screening LCA
- Full scale LCA

The ecological effectiveness can include an individual phase of the product's life, or its entire life cycle with all material and energy flows. In any case, the LCA must follow the requirements of DIN EN ISO 14040 and DIN EN ISO 14044.

The economic effectiveness can either reflect a manufacture viewpoint (for internal use) or a customer viewpoint (for external use). For calculating the LCC, it is favourable to use capital expenditures (CAPEX) or operational expenditures (OPEX).[10]

2.2 Application of eco-tools

In order to support the development of products with improved environmental characteristics, various international standards for environmental management (e.g. ISO 14000 series, EMAS, etc.) and eco-tools (e.g. LCA, ECM) have been developed; most of which incorporate the life cycle approach (cradle-to-grave). Their application is intended for the entire range of stages through the product lifecycle management (PLM) process of a company, so as to not require a radically different approach all together[11]. Such an approach is meant to ensure

[1] Herein, product can refer to product component, industry technology or system solution

environmental considerations are embedded in an organizations routine decision making process.

Using the ECM as an example, one can see the many opportunities for use through an organization's PLM (Figure 2).

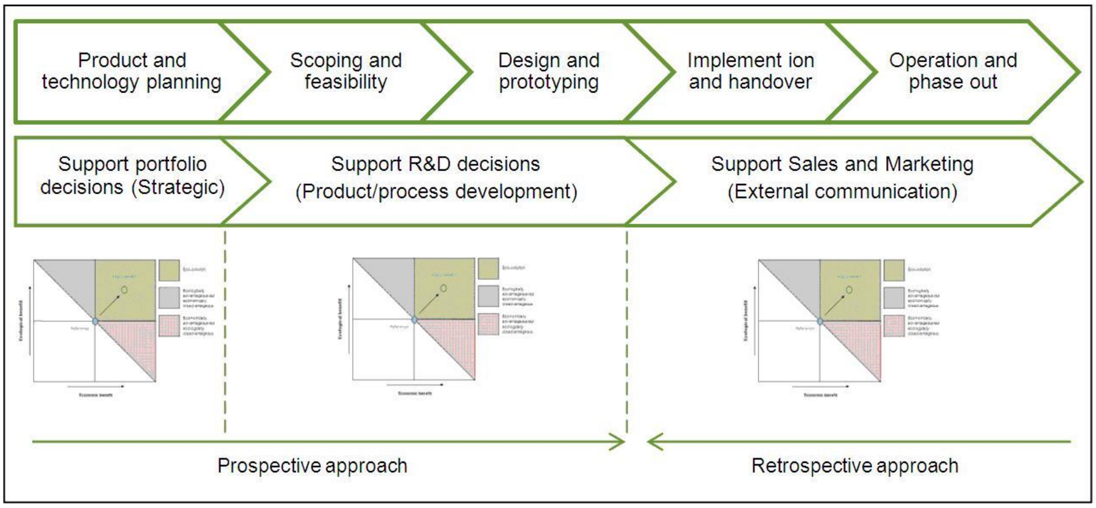

Figure 2. Application of the Eco-Care-Matrix (ECM) in the product lifecycle management (PLM)

The ECM can be utilized in the front end of the PLM process, primarily for internal purposes such as supporting portfolio decisions that are more strategic in nature. Target users would typically be product portfolio managers and those involved in the scoping and exploratory stages of product design. Alternatively, the ECM can be used in the product development phase to support R&D decisions such as material or manufacturing technology comparisons, with designers or engineers as the target users. Furthermore, the ECM can be utilized in the latter half of the PLM process, primarily for external purposes such as supporting the various communication, sales and marketing functions[12]. The former applications are typically seen as more prospective in nature, while the latter more retrospective[13].

To date however, eco-tool and methodological development has been a predominant factor over a focus on the actual use of the tools in everyday management practice [14]. The institutionalization of eco-tools by organizations into routine decisions is therefore less understood, especially for those organizations with little or no prior experience. The following section aims to address this fact by indicating how capabilities are obtained.

2.3 Adoption of eco-tools

Institutionalization Theory describes the adoption process of an innovation (in this case an eco-tool such as the ECM) into a company from the onset of its idea generation and development to the latter stages in which is fully integrated within the routine activities, (in this case the product development or other PLM processes). It divides this process into three distinctive stages Figure 3, which are further explained below.[15]

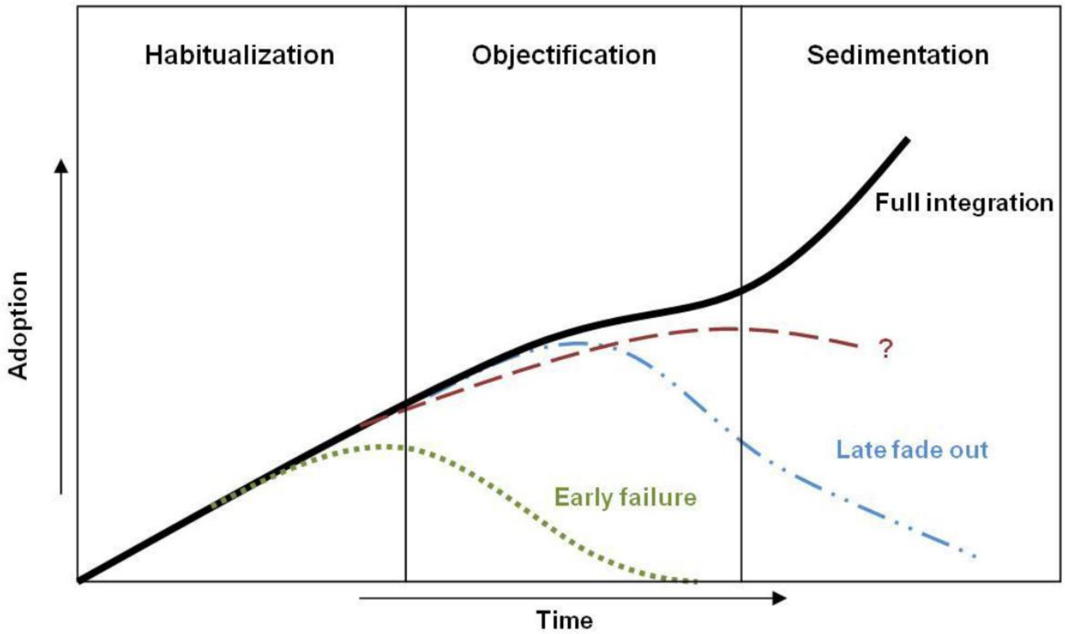

Figure 3. Institutionalization of the Eco-Care-Matrix (ECM)[16]

The first stage is referred to as the *habitualization* stage and is typically characterized by fewer adopters of the innovation. Relating this to the use of the ECM, only one organizational unit or function (EHS specialist) adopts the eco-tool or perhaps its use is restricted to a few applications where only a limited number of ECM case studies are performed. Also in this stage, the reasons for applying the ECM can be motivated by many drivers (e.g. for internal use to support environmentally conscious design or for external use to provide environmental documentation, etc.). Regardless of the motivation, all drivers must create the notion that there is benefit from using the ECM (e.g. that it can improve environmental performance or respond to customer inquiries). At this early stage of the process however, technical and economic factors as well as political aspects largely affect the adoption process.

The *objectification* stage represents the second stage whereby the innovation begins to be more widely accepted and used within an organizational context – a consensus must therefore be achieved amongst a larger set of stakeholders. Consensus is determined two ways: first, by gathering information from many sources in order to justify the adoption; and second, through a champion who can promote the innovation. Using the ECM as an example, a consensus on how to proceed with its application by the various users must be reached in order to further develop in ECM capabilities and reach a broader application. This can be achieved if there is an environmental champion who can justify the application needs and promote ECM use. This stage is cited as being the most crucial in the adoption process because it ultimately determines the fate of the innovation.

The last stage in the adoption process is the *sedimentation* stage. This is the point at which the innovation has been fully integrated into the formal structures of an organization and is spread across a vast group of actors. Here, the champion no longer needs to promote or show the benefits of its use. However, it takes a large commitment from any organization to reach this stage, not to mention both economical and physical resources. It is therefore more unlikely that the innovation is abandoned at this stage, unless there is a lack of demonstrable results.

Referring once again to Figure 3, the progression across the various stages thereby corresponds to different levels of institutionalization. The upward curve indicates full integration of the innovation while the downward curves indicate when an organization ceases to commit to further implementation[17].

There are a number of critical organizational factors necessary to ensure successful institutionalization. These include:

- Justification for the adoption – where the eco-tool must fulfil needs and expectations of the organization.
- Presence of a champion – where this person's role is to promote, validate and ensure advancement across the various stages.
- Central position of the champion – whereby this individual has some form of influence
- Openness and flexibility to unexpected results – where if unexpected results are reached, a learning process occurs to better understand and deal with.
- Internal support – management support as well as policies, time and other resources are needed to support the use of eco-tools to ensure its continuance.
- Influence of opponents – where opposition towards the eco-tool is bound to arise, there must be sufficient ability to not less this influence the implementation process significantly.[18]

3. Design and methods

The following section outlines the methodological approach taken in this paper.

3.1 Pilot application – Siemens AG

This section describes the overall pilot application, from its motivation and general outline. The Industry Solutions Division of Siemens has been using the ECM methodology since 2009, and has more recently made its use mandatory for all green solutions that the Division offers[19]. However, as a multinational conglomerate working with a broad-ranging portfolio in various other Sectors and Divisions, Siemens AG recognized that the ECM had to be further refined and standardized for the other organizational units who were not currently using it. As a result, the Siemens AG Eco-Care-Matrix Pilot Application was initiated in late 2011.

Three Business Units from two Sectors of Siemens AG, in the fields of Energy and Industry, chose to participate in the pilot application; those being Wind Power (E W), Oil and Gas (E O) and Drive Technologies (I DT). However, for the purpose of this case study, only the results of one Business Unit will be discussed in greater detail, that being E W.

The aims of the pilot were manifold: The quantitative results would be used by Corporate Technology (CT) to further develop the ECM methodology and review criteria; User feedback would be gathered from the participants on their experiences and Corporate Environment, Health and Safety (CHR EHS) would use this to further develop an official internal guideline for the ECM application and use; In the case of E W, the Division aimed at using the results to determine whether or not the ECM could be rolled out company-wide to support either the product design functions (to support environmentally conscious design) and/or the communication and sales functions (to provide external environmental documentation). Table 1 summarizes the various goals of the participants.

Table 1. Purpose of the Eco-Care-matrix pilot application

CT	CHR EHS	E W	E O	I DT
Development of standardized methodology and review criteria	Development of organization-wide guideline for application and use	Feasibility of application and use throughout PLM process: Internal use (to support environmentally conscious design) External use (to provide environmental documentation)	Feasibility of application and use throughout PLM process: External use (to provide environmental documentation)	Feasibility of application and use throughout PLM process: External use (to provide environmental documentation)

Each participating Business Unit was to select a set of products from their portfolio to compare using the ECM methodology. The quantitative results of each selected case were then to be presented to various organizational stakeholders in the respective Business Unit in order to gain feedback from the potential users (e.g. product portfolio managers, project managers, engineers, sales and communication representatives). Further details about the case performed in E W are presented in the following section.

3.2 Case study – Siemens Wind Power

This subsection describes the data collection and modeling of the ECM case in E W: The product examined in this case is a rotor blade that is suited for the SWT-3.6-120 wind turbine. It is not a stand-alone product sold to the customer but a component that is part of an overall system solution. The original blade design (herein, referred to as B1) acted as the reference to its successor (herein, referred to as B2). The successor, B2 was an optimized design featuring material reduction and the ability to produce more annual energy. The functional unit selected was therefore the ability of each blade to produce energy; per megawatt hour (MWh) produced based on an annual energy production (AEP) at 7.5 meters per second (m/s).

E W was initially interested in determining the use of the ECM for both internal and external purposes whereby results could be used to support environmentally conscious design and to provide external environmental documentation respectively. As a result, two ECM studies were carried out in order to reflect the manufacture viewpoint and customer viewpoint; herein, referred to as ECM1 and ECM2.

Regarding the ecological effectiveness, a full-scale LCA was conducted in accordance to ISO 14040 and 14044 standards in order to compare the blade designs. The analyses focused on the global warming potential (GWP) using the ReCiPe methodology. Although there were a number of other impact categories that could have been chosen, GWP was selected because it was thought to best reflect stakeholder values. Figure 4 provides an overview of the system boundaries and modeling choices made in the LCAs, subdivided into resource extraction and raw material preparation, component manufacturing, product assembly and installation, operation and maintenance, decommissioning and disposal. For the installation, operation and maintenance life cycle phases, values were based on a LCA performed for the corresponding turbine (full product) and allocated by component weight. Capital goods, such as buildings, production moulds and machinery, were not included in the analysis.

The majority of data was collected on site and modeled using the EcoInvent v.2 database and SimaPro software. Regarding material inputs both direct (materials ending up in the blades) and indirect (help materials that end up as production waste) were included. The only supplier-specific data used was the transport modes and distances for the core materials. Production consumption values were based on annual facility consumption data, which was then allocated to each blade based on weight and production values. During the operation and maintenance phases, no electricity or material consumption is typically used for the blade so this was considered negligible.

Regarding the economic effectiveness, results for the first study (ECM1), incorporated life cycle costs from the manufacturing viewpoint, particularly the F price, service and warranty costs. Results for the second study (ECM2) incorporated life cycle costs from the customer viewpoint, representing the total cost of ownership (TCO) (e.g. purchase price, maintenance, decommissioning and disposal costs). Table 2 gives an overview of the LCCs included in each ECM.

Table 2. Life cycle cost inclusions

MANUFACTURER VIEWPOINT - ECM1	CUSTOMER VIEWPOINT – ECM2
F price (R&D, production and admin costs)	Product price
Use (planned maintenance)	Installation costs
Warranty	Use (planned maintenance)
	Insurance
	Dismantling
	Disposal

This subsection describes the qualitative aspects of the workshops and the questions used: When the ECM study results were obtained, the ECM concept and findings were presented to three different groups of organizational stakeholders. A series of questions were later asked at the end of the presentation, in order to gain stakeholder feedback regarding perceived relevance and usefulness of the ECM.

The workshop method was chosen for a number of reasons: the first was due to practicalities often required in an organizational setting. The second was due to the researchers' interest in the way in which the various stakeholders discussed the specific topic as members of a group, and how they responded to each other's opinions and built up a view out of the interactions occurring within the group. As Bryman (2012)[20] states, "emphasis is on interaction within the group and the joint construction of meaning".

Three separate one-hour workshops were held in which the first half hour of each group session was used to present the aim of the meeting, the ECM concept and ECM study results. The remaining half hour of each group session was used for discussion and feedback to a set of semi-structured questions. Workshop participants were selected based on relevance to the topic and potential use of the ECM. None of the participants had any former knowledge of the ECM or extensive experience regarding environmental topics. Table 4 provides an overview of the attendants from each workshop.

Table 3. Workshop details

ORGANIZATIONAL LEVEL	E W blade manufacturing, mixed functions	E W central, engineering functions	E W central, communication functions
ECM RELEVANCE	Internal and external (manufacture viewpoint and customer viewpoint)	Internal (manufacture viewpoint)	External (customer viewpoint)
ATTENDEES	7 persons consisting of project managers, R&D, business excellence and communication functions	6 persons consisting of corporate technology, PLM, R&D and engineer functions	5 persons consisting of sales, marketing and communication functions

The overall aim of the three workshops was stated as "what is the Eco-Care-Matrix and do you think it could be a useful tool in E W?". The first half hour presented the ECM concept, reasons for its development, example uses from another Siemens Sector, the case results from the ECM studies performed and an overview of the semi-structured questions posed in the second half.

It was important to clearly define the concept and reasons for the ECMs development, as this was a new subject for most participants who typically work outside of the environmental field. The reason for showing examples from another Siemens Sector was to demonstrate that even if the ECM activities (LCA and LCC) were new and unknown to most, such activities were not unusual in other Sectors of the organization. The logic being, that if other companies are working with similar eco-tools, why should E W not do so as well? Furthermore, the questions asked to the various stakeholders included aspects on the ECMs perceived relevance (e.g. how relevant is environmental documentation of our product?); evaluation (e.g. could the ECM help you in your daily tasks and decisions?, strengths and weaknesses of the ECM?); and recommendations for use (e.g. what is your final statement regarding the application of the ECM approach in E W?).

4. Results

4.1 ECM for an optimized rotor blade design

In both ECM studies evaluating the manufacture viewpoint (ECM1) and customer viewpoint (ECM2), the product successor (B2) resulted in both a higher ecological and economic effectiveness than the predecessor (B1). From the manufacturing viewpoint, this is mainly due to the reduction in material usage during the manufacturing life cycle phase while from the customer viewpoint, this is mainly due to the increased AEP the optimized blade provides during the operation phase of the products life cycle. However, for the purpose of this paper only the second case study (ECM2) results will be displayed (Figure 5).

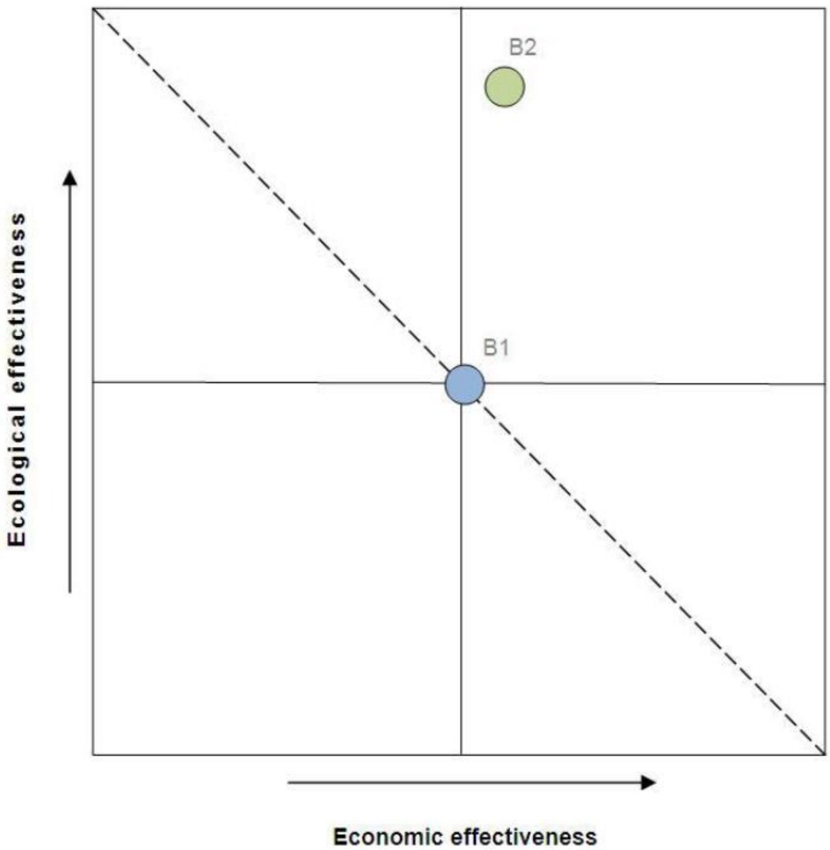

Figure 4. Eco-Care-Matrix for an optimized rotor blade design using customer viewpoint to provide external environmental documentation

4.2 Workshop responses

Tables 4-6 summarize the responses from the various workshops.

Table 4. Responses from E W blade manufacturing, mixed functions

	ECONOMIC EFFECTIVENESS	
ECOLOGICAL EFFECTIVENESS	MANUFACTURER VIEWPOINT – ECM1	CUSTOMER VIEWPOINT – ECM2
Communication representatives were most interested in just LCA results as basis for the development of external environmental communication.	Project Managers and Engineers agreed this is most useful in cases where a wind turbine is produced with a very different technology or different material types. At the component level it could be a nice tool for internal R&D projects.	A significant amount of background data must be made available should customer concerns arise. All agreed that using this information must be handled with extreme care to avoid promising customers something that could potentially change under different circumstances. Difficult to calculate for operation phase due to the product's nature - not energy using but energy producing and reflective of a number of different things (e.g. energy market, subsidies, etc).

Table 4. Responses from E W blade manufacturing, mixed functions

	ECONOMIC EFFECTIVENESS	
ECOLOGICAL EFFECTIVENESS	MANUFACTURER VIEWPOINT – ECM1	CUSTOMER VIEWPOINT – ECM2
Communication representatives were most interested in just LCA results as basis for the development of external environmental communication.	Project Managers and Engineers agreed this is most useful in cases where a wind turbine is produced with a very different technology or different material types. At the component level it could be a nice tool for internal R&D projects.	A significant amount of background data must be made available should customer concerns arise. All agreed that using this information must be handled with extreme care to avoid promising customers something that could potentially change under different circumstances. Difficult to calculate for operation phase due to the product's nature - not energy using but energy producing and reflective of a number of different things (e.g. energy market, subsidies, etc).

Table 5. Responses from E W central, engineering functions

	ECONOMIC EFFECTIVENESS	
ECOLOGICAL EFFECTIVENESS	MANUFACTURER VIEWPOINT – ECM1	CUSTOMER VIEWPOINT – ECM2
Environmental results do not currently influence the decisions for how and which products are developed and decisions are made – currently, cost represents 99.9% of the decision making. LCA data from supplier is impossible to get, and procurement's focus is primarily on price. Interested in development of environmental data for both internal and external use.	When asked, could see a point in using the ECM for technology projects and to compare materials. Could not see the relevance of linking cost to environment as they already make complex cost calculations in PLM. Not interested in another PLM tool but rather to integrate LCA data in the future with existing PLM solutions.	Irrelevant for this group so limited comments given.

Table 6. Responses from E W central, communication functions

	ECONOMIC EFFECTIVENESS	
ECOLOGICAL EFFECTIVENESS	MANUFACTURER VIEWPOINT – ECM1	CUSTOMER VIEWPOINT – ECM2
Communication representatives were most interested in more LCA results - as a modern company and for competitive reasons; must be able to document environmental performance.	Communication representatives were most interested in more LCA results - as a modern company and for competitive reasons; must be able to document environmental performance.	Communication representatives were most interested in more LCA results - as a modern company and for competitive reasons; must be able to document environmental performance.

4.3 Outcome for the Siemens AG pilot application

The other two Business Units (E O, I DT) had similar findings to E W and therefore, all decided they would not use the ECM as a regular tool for the time being. In the project members' view, they supported the company having a tool available, which compares ecological and economic benefits but did not agree that it should be a mandatory requirement for the Business Units. It was stated that the use of the ECM as a routine method was too complex to simply be applied without expert knowhow, and that there was a need to determine the correct and most relevant case examples for application in which a guiding ECM expert would be available to analyze. Furthermore, all Business Units agreed that the current focus and efforts should rather be on the extensive use of LCAs and EPDs for environmental documentation.

Positively, Siemens AG achieved an increase in experience with use of the ECM, in which the methodology was applied to a larger scope of product types within difference Sectors. An internal and voluntary guideline for performing an ECM is expected to be developed, based on the experiences gained from the pilot application. Furthermore, the methodology and review tools for performing an ECM study were further developed. It can therefore be stated that the ECM methodology has grown in maturity.

5. Discussion and managerial implications

In this section the results are discussed against the theoretical framework with a final summary of managerial implications.

Overall, there was a general interest for an eco-tool. This can be confirmed by the number of attendees that participated (70 percent confirmation of attendance), in addition to the strong support and interest for more environmental data. In one of the workshops a sales officer was quoted as saying, *"[more environmental data is] absolutely needed – one project we previously worked on was driven entirely by environmental information".* There was consensus from all groups on this fact, with potential uses both internally for product related environmental information, decision support and product improvements in the R&D stages, as well externally for customer related environmental information.

However there was some opposition to the combination of cost and environmental data (thereby opposition to the ECM as the correct eco-tool). In another workshop, a PLM representative also reinforced the need for more environmental data but questioned the combination of it with cost related data, saying

> *"I don't know why we are combining it [environment] with cost actually; it should be isolated…but I think it's a little naive to think that maybe we will get so many more customer points or a better image with this tool. Regardless, the product life cycle assessment, from extraction to recycling, is a must for PLM and I think we have to do this. But whether we couple environmental impact with cost on this chart, which I think can be questioned".*

Here, he also questioned the ECMs application for external marketing purposes but highlighted its usefulness internally for prospective studies in R&D.

Furthermore, much uncertainty was expressed about the method in which customer cost is calculated and the combination of environmental data with cost data: another PLM representative stated,

> *"I'm not sure that the ECM is the right tool to deal with cost because honestly, it's far more complex and has to be calculated based on the different markets, platforms, segments of the markets and so on. And I think that will be far too complex to see a product improvement on the environmental side and all those different perspectives… And, this would be a lot of work which I'm not sure would benefit so much".*

While another, in concern of an additional PLM tool, notes,

> *"Its just that we have a tendency to have a lot of different tools, and if the tools are not interlinked [with PLM tools] then they are lost… We should spare the effort and focus on slim lining the portfolio tools within a company".*

After which the representative stated that in a few years time, LCA data could perhaps be incorporated into the already existing PLM tools for cost, when the PLM tool reached a higher maturity level. Finally, a communications representative reaffirms this by stating, *"this would be nice to implement 4-5 years down the road…I think we need to be very careful with the customer cost aspect".*

It was therefore decided at E W that there was currently no interest in the ECM tool for external communication, due to the difficulty in correctly calculating customer costs so it would not be used to express cost effectiveness from the customer viewpoint; There was some interest expressed for the EMCs internal use in order to express the cost effectiveness from the manufacturing viewpoint of technology projects or material comparisons; Finally, there was a high interest in environmental data (e.g. LCA) without the combination of cost data, both for internal decision making and communication and for external documentation.

Perhaps this is simply a matter of maturity – where the use of LCAs to obtain environmental information would be the first eco-tool employed before integrating a more complex tool, like the ECM, measuring additional factors such as cost. The use of LCAs could therefore be expanded and as the organization becomes more accustomed to these activities over time, the process could then be expanded to incorporate the ECM (cost aspects).

Relating back to the institutionalization framework, the role of an eco-tool can change over time according to the different institutionalization stages. For example, if the organization is within the *habitualization* stage then the eco-tool acts as a learning tool. As the organization progresses into the other stages, the role of the eco-tool slowly shifts from retrospective to prospective use. This changing role is connected to the learning processes within a company.

This is what is seen in the case of E W. Environmental issues are a new field of discussion for most of the participants. The discussion regarding the ECM created a learning opportunity within the workshops. Despite all of the discussion and disagreement between the participants regarding the methodology for calculating costs, it was seen as an essential requirement in order for the participants to incorporate the new information and give meaning to the ECM. It did not matter that there was little certainty about the future use of the ECM as a prospective eco-tool, the ECM study achieved the successful outcome of getting a variety of functions across the PLM process, at various organizational levels, involved in the discussion.

It is still too early to speculate if the ECM will be adopted as a routine eco-tool in E W. But the mere fact that the group was interested in further examples is promising. The feedback and experiences gained from this pilot will therefore help the 'champions' readjust according to users' needs. After which, more case studies can be performed and disseminated to a wider audience. It could be implied that this will help to secure a continued discussion of the topic resulting in a progression towards the second stage, *objectification.*

In line with Siemens AG's claims, there is much flexibility with using the ECM: It can function as a centralized or decentralized, voluntary tool with support from the Corporate functions of Siemens AG; The ECMs application within the various Divisions can be applied from either a top-down or a bottom-up approach; ECM results can be used internally or externally depending on the needs of the Division's PLM process; and ECM application is broad, in that it can be applied at a component or technology level or at a system solution level.

However, the main disadvantage of the ECM as an eco-tool its higher level of complexity to an LCA, meaning that it is even more time consuming and costly to perform and the data required to perform the ECM are more sensitive.

As well, it requires a significant amount of effort and perseverance when implementing something novel in an organizational setting, with the ECM being no exception.

The findings from the E W study were similar to those from E O and I DT whom can also be classified within the *habitualization* stage. This sheds light as to why the ECM has not been expanded further to other Divisions of Siemens. Routine adoption is heavily dependent on the organizational factors (e.g. general consensus as to the ECMs application, the presence of a champion, a high organizational learning value, management support, etc.), and it can be assumed that one or more of these has been missing in each Division.

6. References

[1] Holst, J.C., Mueller, K., Uebelhoer, K. (2011). Sustainable lifecycle engineering at Siemens AG. Conference paper at LCM2011, 28-31 August, 2011, Berlin.

[2] Siemens (2012). Life Cycle Assessments. Webpage. http://www.siemens.com/sustainability/en/core-topics/product-responsibility/management-approach/life-cycle-assessments.htm

[3] Siemens (2012). Life Cycle Assessments. Webpage. http://www.siemens.com/sustainability/en/core-topics/product-responsibility/management-approach/life-cycle-assessments.htm

[4] Siemens (2010, May 11). Environmental Solutions Increase Competitiveness in Mining and Steel Industries. Press Release. http://www.siemens.com/press/en/presspicture/?press=/en/presspicture/2010/industry_solutions/iis201005406-01.htm

[5] Siemens (2011, Fall). When is Green Really Green? Pictures of the Future. http://www.siemens.com/innovation/apps/pof_microsite/_pof-fall-2011/_html_en/environmental-analyses.html

[6] Saling, P., Kicherer, A., Dittrich-Krämer, B., Wittlinger, R., Zombik, W., Schmidt, I., Schrott, W., and Schmidt, S. (2002). Eco-efficiency analysis by BASF: the method. *International Journal of Life Cycle Assessment,* 7(4), pp.203-218.

[7] Wegener, D., Finkbeiner, M., Geiger, D., Olsen, S. I., Walachowicz, F. (2009). Comprehensive approach to energy and environment in the EcoCare program for design, Engineering and Operation of Siemens Industry Solutions. Conference paper at RISO International Energy Conference, 14-16 September, 2009, Copenhagen.

[8] Wegener, F., Finkbeiner, M., Holst, J. C., Olsen, S. I., Walachowicz, F. (2011). Improving energy efficiency in industrial solutions – walk the talk. Conference paper at RISO International Energy Conference, 10-12 May, 2011, Copenhagen.

[9] Siemens (2012). Draft internal guideline for performing Eco-Care-Matrix. Munich: Siemens.

[10] Wegener, D., Finkbeiner, M., Geiger, D., Olsen, S. I., Walachowicz, F. (2009). Comprehensive approach to energy and environment in the EcoCare program for design, Engineering and Operation of Siemens Industry Solutions. Conference paper at RISO International Energy Conference, 14-16 September, 2009, Copenhagen.

[11] Cramer et al. (1994). within Tukker, A., Haag, E., Eder, P., 2000. Eco-design: European State of the Art. Part I: Comparative Analysis and Conclusions. An ESTO project report prepared for the European Commission – Joint Research Centre Institute for Prospective Technological Studies.

[12] Wegener, F., Finkbeiner, M., Holst, J. C., Olsen, S. I., Walachowicz, F. (2011). Improving energy efficiency in industrial solutions – walk the talk. Conference paper at RISO International Energy Conference, 10-12 May, 2011, Copenhagen.

[13] Frankl, P. & Rubik, F. (2000). *Life Cycle Assessment in Industry and Business. Adoption Patterns, Applications and Implications*. Dordrecht: Springer Publishing.

[14] Frankl, P. & Rubik, F. (2000). *Life Cycle Assessment in Industry and Business. Adoption Patterns, Applications and Implications*. Dordrecht: Springer Publishing.

[15] Tolbert, P. S., Zucker, L. G., 1996. The Institutionalization of Institutional Theory. In Clegg, S. R., Hardy, C., Nord, W. R., (eds.): Handbook for Organization Studies. London: Sage, pp. 175-190.

[16] Frankl, P. & Rubik, F. (2000). *Life Cycle Assessment in Industry and Business. Adoption Patterns, Applications and Implications*. Dordrecht: Springer Publishing.

[17] Frankl, P. & Rubik, F. (2000). *Life Cycle Assessment in Industry and Business. Adoption Patterns, Applications and Implications*. Dordrecht: Springer Publishing.

[18] Baumann and Tillman (2004)

[19] Siemens (2011, Fall). When is Green Really Green? Pictures of the Future. http://www.siemens.com/innovation/apps/pof_microsite/_pof-fall-2011/_html_en/environmental-analyses.html

[20] Bryman, A. (2012) *Social Research Methods, 4th ed.* Oxford: Oxford University Press.

APPENDIX B

Ecodesign procedure for Siemens Wind Power (includes versions 1 & 2)

**omitted in online version, restricted internal documents*

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