FACULTY OF TECHNOLOGY

Analysis of Design for Environment Requirements for Future Consumer Electronics

Sudeep Parajuli

Industrial Engineering and Management

Master's Thesis

December 2021

ABSTRACT

Analysis of Design for Environment Requirements for Future Consumer Electronics

Sudeep Parajuli

University of Oulu, Industrial Engineering and Management

Master's Thesis 2021, 74 pp. + 1 appendices

Supervisor(s) at the university: Harri Haapasalo, Jukka Majava

The scope of the study was to outline the critical areas of 'Environment' as a key stakeholder of product development. The aim of the research was three-folded. First, in the literature part, the aim was to understand design for environment (DFE) and capability creation concepts and resolve how to combine them into a concept. Second, in the empirical analysis part, the aim was to find the generic design for environment stakeholders and requirements for product development in the electronics industry. Finally, in the further analysis and discussion part, the methods and concepts to combine stakeholders and requirements for design for environment were generated at a generic level.

A literature study was utilized to understand the topic, where general ideas and aspects around design for environment and capability creation were collected. An empirical survey was then conducted by interviewing experts and managers at three electronics and high technology companies in Finland. The survey was conducted via an online Teams meeting guided by a questionnaire related to design for environment and its related aspects. Finally, the analysis of the answers was performed using common knowledge and understanding.

DFE is a product development approach that seeks to enhance a product's environmental attributes throughout its lifecycle. The ultimate objective is to meet sustainability goals, and the early involvement of design for the environment facilitates product development in creating sustainability capabilities. Design for environment and sustainability capability creation are counterpart activities that support each other in a cycle loop. They both require and utilize identifying and assessing critical environmental stakeholders during the product development process for long-term sustainability. The empirical study

indicates that there are two types of environmental stakeholders. They are internal stakeholders and external stakeholders. Business groups, design teams, quality teams, and experts are the internal stakeholders within the organization that participate actively in the product design and development process and have power in the decision-making process. Customers, suppliers, investors, and peers are the external stakeholders who strongly influence the product development process but do not have decision-making power. The key environmental stakeholders present essential environmental requirements that should be considered in making distinct changes and improvements in the new product development process. The central design for environment requirements are legal requirements, customer requirements, materials and energy requirements, and voluntary requirements.

In conclusion, it can be stated that design for environment is a lifecycle thinking approach to product development that supports continuous improvement and development of sustainable products. Therefore, it is critical to identify and prioritize the key environmental stakeholders and their environmental requirements for better decision-making and focusing on fulfilling the sustainability targets. This study highlights the key areas of the environment where companies, especially the electronics industry, have to rethink the design for environment activities and recognize the concept to develop in an effective and organized way.

Keywords: Design for Environment, Capability Creation, Stakeholders, Requirements

FOREWORD

This Master's thesis was conducted at the Faculty of Technology at the University of Oulu during the autumn semester of 2021. The study is a part of the M.Sc. in Industrial Engineering and Management, Product Management. This thesis study is one of the first that emphasizes outlining the key areas of 'Environment' as a key stakeholder.

I want to express my sincere gratitude to my supervisors Prof. Harri Haapasalo and Associate Prof. Jukka Majava for allowing me to take this thesis project. I feel myself luckiest to work under the supervision of Harri and Jukka. Their guidance and valuable suggestions and feedback always motivated me to work and perform better. I attribute the successful completion of this thesis work to the continual enthusiasm and effort of Harri and Jukka. I am thankful to them for helping me in every step of this thesis work, finding contacts with the companies, and the suggestions given for writing the report. It will always be an honor to be reckoned as one of their disciples. I hope and wish to work under their supervision in the future.

I am grateful to all the interviewees from all the companies who helped me by sharing their knowledge and providing some invaluable information that supported the completion of my thesis study.

I would like to say a heartful thank to my wife, Mina Malla Thakuri, any my family, my mom and my brother, for their unconditional love and support in various ways throughout the thesis period, and my life in general.

I cannot forget my friends who always encourage and inspire me in every steps of my life and who have helped me whenever I was in need.

Oulu, 01.12.2021

Sudeep Parajuli

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CC	Capability Creation
DFE	Design for Environment
DFX	Design for X
ER	Environmental Requirements
ES	Environmental Stakeholders
NPD	New Product Development
PD	Product Development
RQ	Research Question

1 INTRODUCTION

1.1 Background

Over the few years, the electronics industry has transitioned from an end-of-pipe industry and a process-oriented industry to a product-oriented one (Boks and Stevels 2007). Sustainability aspects of the circular economy have become the driving aim for technological and economic developments as the electronics industry become aware of their environmental impacts and are more concerned about such issues (Kuo et al. 2001; Telenko et al. 2009). Therefore, the design of products with a minimum environmental effect has become more essential, and the electronics industry has become more aware of reducing the total environmental impact of the products. Each phase of the product lifecycle is essential, from the production phase of the product to its use and disposal phase. As environmental legislation and consumer demand for sustainable and eco-design have been increasing rapidly, the industries have become more concerned about ensuring the recovery of the products and materials at the end of their lifecycle (Mathur 2007). It is thus required to have a new approach to product design to implement safe disposal and recycling, reusing, and recovering the products by taking into consideration all phases of its lifecycle.

Design for Environment (DFE) also sometimes termed as eco-design, green design, sustainable design, lifecycle design, environmentally conscious design (Lagerstedt et al. 2003; Mathur 2007; Telenko et al. 2009), aims at enhancing environmental impacts over the product life cycle by integrating environmental considerations into product design (Telenko et al. 2009). Therefore, the scope of the industry's implementation of DFE practices is crucial to its competitiveness in today's dynamic business environment.

1.2 Problem definition

Product design must address various customer, technical, legal, and other stakeholder requirements. Design for X (DFX) method aims for better product design (Tolonen et al. 2017), thereby addressing various customer requirements while considering the product lifecycle. DFX addresses early product development, continuous improvement, and

capacity creation in a systematic way (Lehto et al. 2011). Effective product development is a prerequisite to meet the customers' demands and needs to achieve competitive goals. DFX concepts have been extended to address several relevant aspects, including the environment. It has been widely discussed in the literature that suggests what the product should be like in the DFE. There are different issues, such as legitimate issues, urgent types of requirements, and direct issues listed in the existing literature. However, there still lacks research on how sustainability capability creation as a corresponding concept works and what is needed during product development to make the environmental aspect and circular economy work. Currently, the industry does not have any specific guidelines for sustainability capability creation to support future circular economy principles and business models. Therefore, it is necessary to develop and validate the particular guidelines in under-utilized and emerging areas of DFE.

1.3 Research aims and research questions

The aim of this master thesis is three-folded. Firstly, a general understanding of design for environment and capability creation concept is gained by assessing and integrating the available literature outline, thereby combining design for environment (DFE) and capability creation (CC) into a concept. Secondly, an empirical study is conducted to understand the generic DFE requirements for product development in the consumer electronics industry. Finally, the research focuses on clarifying the requirements and stakeholders. The results are thus, analysed and integrated to describe the methods and concepts to combine stakeholders and requirements for DFE at the generic level during the product development and to give further suggestions for implementation practices. The above research aims lead to address the research questions as shown in Figure 1 for this research study:

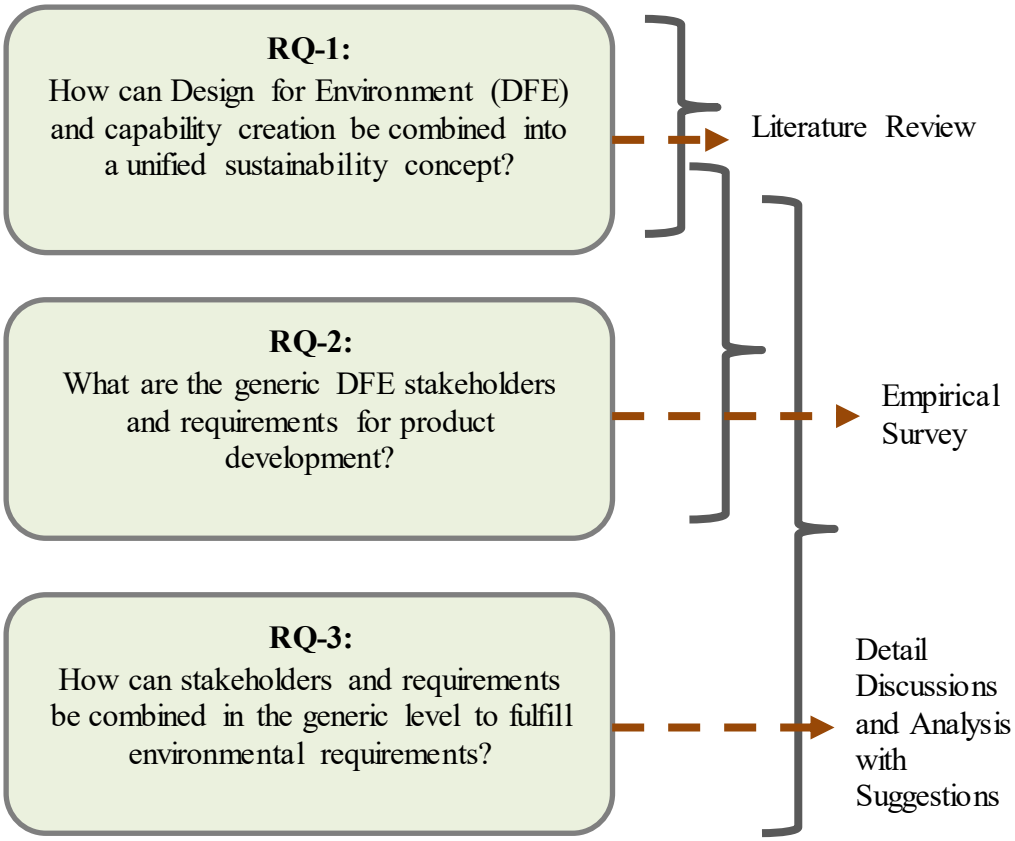

Figure 1. Research questions for the current study

1.4 Research approach and process

In this thesis, the research on DFE is concentrated mainly on describing and analysing the environmental requirements and stakeholders in the consumer electronics industry. Moreover, literature on basic concepts of DFX and sustainability capability creation are compressed to gain a general understanding on how the design for X, where environment as a stakeholder, can be combined to capability creation into a concept.

The current research is explorative and is based on literature review and qualitative empirical data. A qualitative approach was chosen for this research study because it focuses on developing an understanding of the subject instead of analytically proving or disproving a specific hypothesis.

The research in this study follows a multi-methodological approach, including a range of diverse sources, approaches, and theories to address the research questions. As a result, the method was not linear. Rather than that, it was accomplished through a continuous and iterative process that emerged as a result of interaction between theoretical foundations and empirical data. The empirical data were obtained through a literature review, company surveys, and semi-structured interviews with company representatives from the electronics industry. Analyses and syntheses are constructed based on critical thinking, simplicity, and clarity of expression.

At the beginning of the study, the initial understanding of the DFX topic focusing on the principle of the DFE and Sustainability Capability Creation is gained through existing literature to outline requirements from the environmental side. With most journal articles, the research materials are searched mainly through Google Scholar, the University of Oulu Library database (Oula-Finna), and Science Direct. The study focuses on using the most relevant articles as literature. The second part of the research is the empirical study and analysis based on preliminary interviews with case companies and literature used to analyse the environmental requirements and stakeholders for the electronics industry. The third part of the study is more constructive. After getting the initial answer to RQ2, a detailed discussion is conducted to outline the sustainability capability creation framework through in-depth analysis of the first and second parts and a combination of literature and empirical study analysis.

1.5 Structure of the thesis

The thesis consists of five chapters with various themes. The following is a breakdown of the various chapters with respective themes and sub chapters.

Chapter 1: Describes about the background and introduction to the research study. It addresses the current research problems in the context of environmental aspects of product development for future consumer electronics. The scope of the research together with research questions and research approaches are described in this chapter.

Chapter 2: Comprises of the theoretical foundation of the research study. Presents general concepts for design for X, mainly focusing on principle of the design for environment and sustainability capability creation concepts.

Chapter 3: Defines the methodology for current research study. Describes the empirical research approaches.

Chapter 4: Current state analysis of design for environment concept in the electronics industry. Discusses the most important types of requirements in sense of environment and the stakeholders who presents and carry on those requirements in particular in electronics industry.

Chapter 5: Discusses the key stakeholders and activities of environment. Presents a detail discussion on how environmental stakeholders and requirements can be combined in a generic level to fulfil the sustainable requirements based on the theoretical and empirical results and analysis.

Chapter 6: Summarizes the results and discusses the answers to the research questions and reviews the most important contributions and conclusions. In addition, suggests and recommends topics for further research.

2 LITERATURE REVIEW

2.1 New Product Development and design (for environment)

New product development is the process of discovering, developing, and introducing new products to the market. First, product ideas are identified and evaluated for feasibility before moving on with the development process. Then, after the concept has been screened, the new product development process is commenced, including several stages before a new product is introduced. (Pahl et al. 2007) Figure 2. shows Ulrich and Eppinger's (2008) generic new product development process which is considered as the most recognized new product development model.

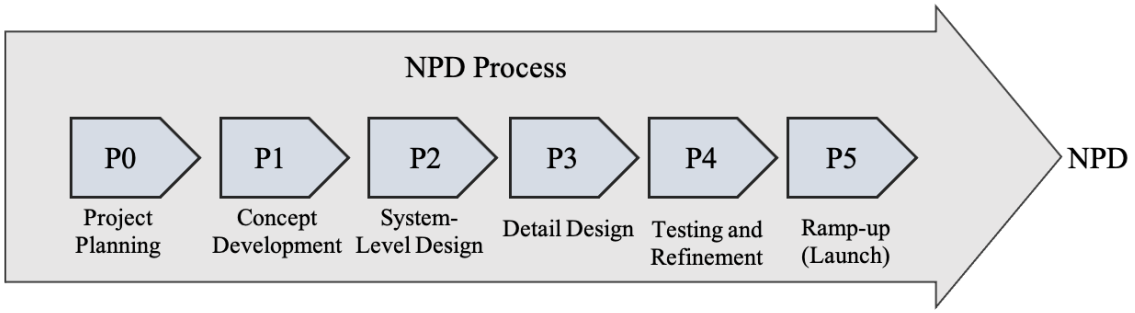

Figure 2. Generic new product development process (Ulrich & Eppinger 2008, 4th edition)

Product development usually considered a multidimensional activity (Mathur 2007; Lagerstedt et al. 2003), is undergoing a continuous transition in the electronics industry (Helo 2004; Belt et al. 2008; Zeidler 2008). It is typically characterized by a large organizational structure, the engagement of a large number of individuals, and a diversity of areas such as research, design, marketing, production, distribution, and management (Mathur 2007; Lagerstedt et al. 2003).

The product development process is characterized by continuous analysis and interpretation at various levels of detail, which is carried out in an iterative way. In general, design work always begins with an analytical phase in which the problem is identified and explained, along with the overall goal. The problem analysis should be followed by developing a requirement specification and generating ideas and concepts (Mathur 2007).

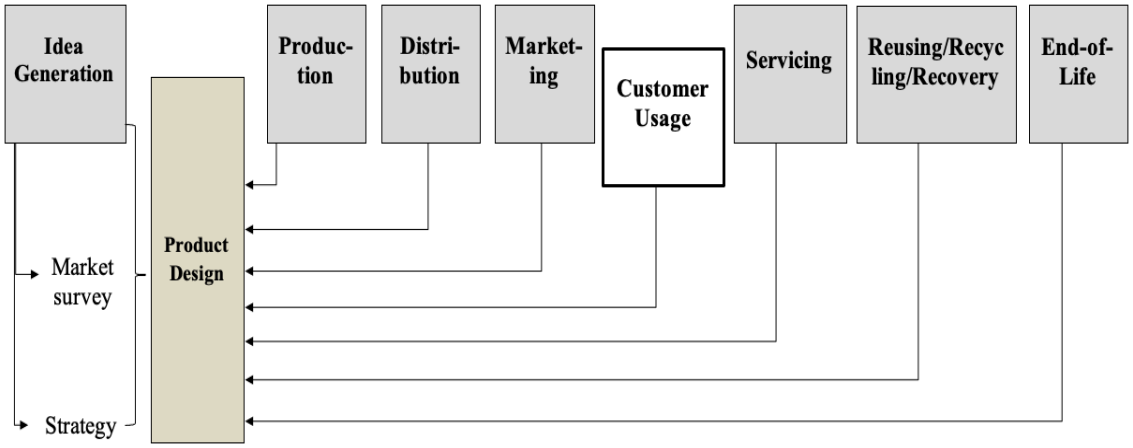

Figure 3. Product design process representation (modified from Rose 2000).

Figure 3 illustrates how key decisions made throughout the product design process may impact decisions made during the production, distribution, marketing, customer usage, service, reusing, recycling, recovering, and end-of-life phases of the product's life cycle. Within the product development process, various stages must be performed. It all starts with generating an idea, followed by product definition or product planning, conceptual design, detail design, and embodiment design. The design phase has the most significant influence on the product's environmental impact since it is the most time-consuming phase. (Rose 2000). It is thus critical to use product information pertaining to environmental concerns at an early stage in the product design and development cycle.

Several studies have stressed the importance of early phases in the product development process (Gatenby and Foo 1990; Harkonen et al. 2009; Lau et al. 2007; Yang et al., 2007). Therefore, DFE must integrate and adapt in the early phase of the product development process to accomplish environmental product improvements. It is usually assumed that early product development phases have the greatest effect on the environmental aspects of the product (Lagerstedt et al. 2003). Design for Environment (DFE) addresses different aspects of environmental sustainability during the product development activities, including appropriate material utilization, analyzing the product usage process to minimize environmental impact, energy consumption and efficiency, reducing industrial residues during production, material recovery, reuse, recycling, and considering the design for end-of-life (DeMendonca and Baxter 2001; Fiksel 1993; Junning et al. 2003; Rose 2000; Telenko et al. 2008).

Figure 4 depicts a straightforward model of product development processes, emphasizing the relationship between the degrees of freedom in product design and the information and data about the new product at various phases of design development. The design process can be represented by the curves, which reflect the increasing amount of product knowledge and the decreasing amount of design flexibility as time progresses. When designing a new product, the amount of knowledge available at the beginning is limited. However, there is also a significant amount of freedom in how the product's design takes place, such that the environmental aspects of the product may be recognized and included in the design. This product development stage is termed the early product design phase or early product planning phase. As the product develops, the amount of information available about the product grows, but at the expense of design freedom. A sustainable solution generally requires substantial improvements and re-thinking of product systems, and as a result, decisions made during the early phases of product development are critical. (Mathur 2007; Lagerstedt 2003; Lagerstedt et al. 2003; Rose 2000; Lehto et al. 2011)

When an intellectual breakeven point is reached, a conceptual phase of the product is established, referred to as the intermediate design phase (Lagerstedt 2003; Mathur 2007). This conceptual design phase calls for the implementation of design for environment requirements or checklists such as material selection (Rose 2000), environmental regulatory requirements, customer requirements, etc. By the end of the process, the company acquires the most knowledge about the product, but the chances of making changes to the design are reduced significantly (Lagerstedt et al. 2003). Therefore, environmental aspects in product design should be considered from the beginning of the

product development process.

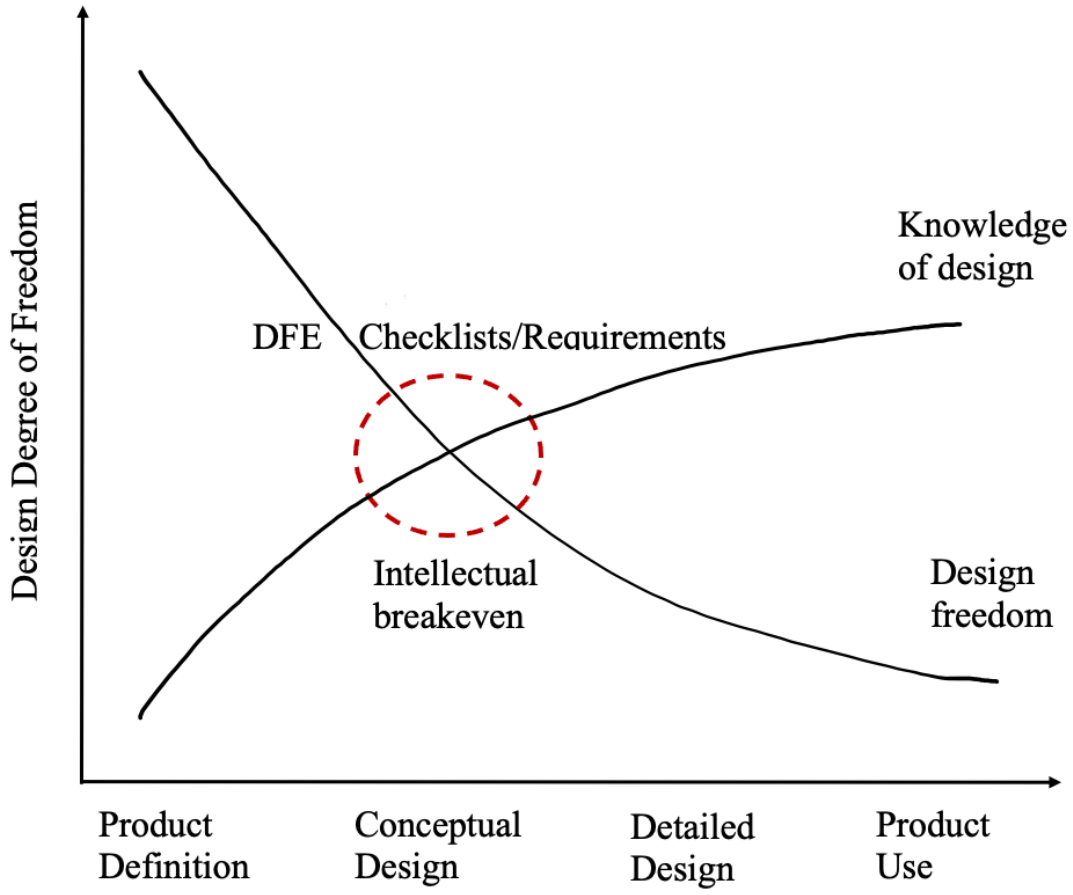

Figure 4. Knowledge and degree of freedom in the product development process (modified from Lagerstedt 2003 and Rose 2000)

2.1.1 Requirements in product design

A number of aspects must be addressed during the product development and design process. Customer requirements must be considered throughout the early stages of the product development process, including appropriate material selection, functional requirements, environmental requirements, and technical limitations. Customer requirements may include functional performance, human factors, physical factors, reliability, lifecycle, sustainability, resource, and manufacturing requirements (Lagerstedt 2003; Mathur 2007). Similarly, other requirements that consider the design performance concerning environmental, health, and safety objectives, referred to as DFE objectives, may include minimizing material and energy consumption and waste throughout the product's life cycle, reducing transportation requirements, reducing workplace health and safety hazards, and manufacturing products that benefit and support the environment and improve the economic condition throughout society (Rounds and Cooper 2002).

2.1.2 The environment – a part of product development

Environmental concerns are essential and should be appropriately addressed. However, in the practical design field, time limits and deadlines require that environmental issues cannot consume an excessive amount of the PD and design process time frame. In general, products are designed based on requirements that include one or two core functionalities and several limitations. Even though it is the primary product function, very few products, principles, or functions can be described using a single criterion; other considerations such as cost, physical lifespan, and appearances are vital factors that influence consumer choices (Luttropp and Lagerstedt 1999). The majority of DFE techniques, on the other hand, are based on a single condition or the primary function. As a result, in addition to the primary purpose, it is necessary to adopt a set of fundamental design requirements while keeping in mind that environmental concerns should also be given high priority in the design process (Lagerstedt 2003). Figure 5 is a pie chart that demonstrates this concept in further detail. As such, design for environment refers to taking environmental aspects into consideration without compromising the other requirements imposed on the product, and design solution should strive to achieve a balance between all of the competing requirements (Lagerstedt 2003; Lagerstedt et al. 2003).

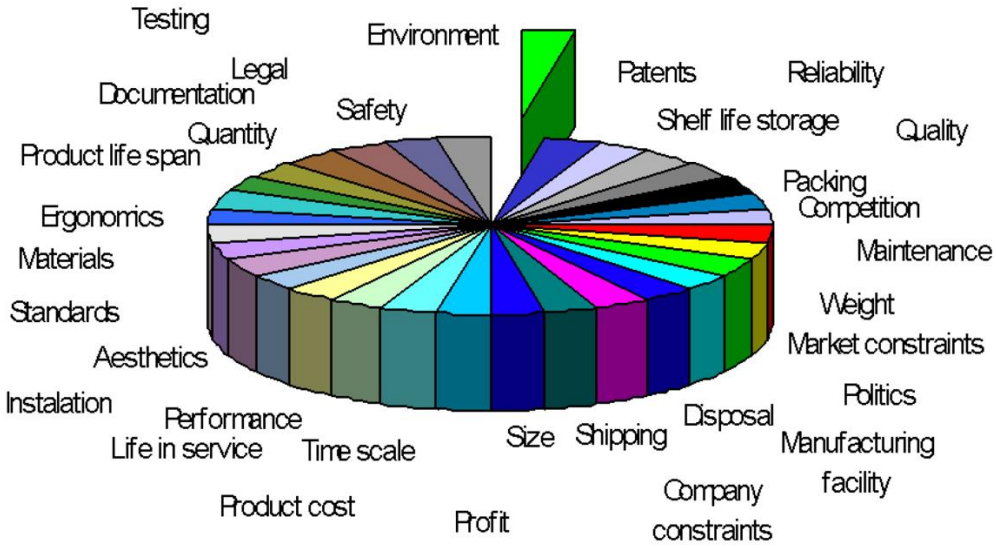

Figure 5. Representation of demands to be addressed during the product (Adapted from Lagerstedt 2003). The figure depicts environment as a part of the product development process.

2.2 Design for X

Product design requirements have continuously increased with the need for significant changes in product design in different aspects. Product developers can no longer utilize the design of products only in terms of their key functional or performance requirements to remain competitive. The product must perform well in all aspects, such as cost, quality, safety, security, reliability, and environmental impact, while contributing to customer satisfaction. Research shows that it is preferable to address the fundamental problem and make efforts to enhance the product rather than simply reacting to the symptoms of the problem. Product improvements are more important, and environmental concerns must be addressed. (Rose 2000)

Design for X is the process of considering X during the product development process. In the Design for X concept, 'Design' means engineering design (Mustonen 2009) whereas 'X' means lifecycle aspect, lifecycle phase, or stakeholders such as manufacturing, assembly, cost, quality, recycling, maintenance, servicing, supply chain, and environment (Halttula et al. 2017; Holt and Barnes 2010; Lehto et al. 2011; Möttönen et al. 2009; Mustonen 2009). DFX provides a practical framework for executing concurrent engineering (Kinnunen et al. 2014; Lehto et al. 2011). The general idea of implementing the DFX concept is to acknowledge all possible 'X' in engineering design so that to create a downstream operation to ease the lifecycle flow of the product and at the same time reduce the costs (Kinnunen et al. 2014; Kuo et al. 2001) and design the product for high-quality lifecycle management and increase the efficiency of the product throughout the product life cycle (Mustonen 2009). Moreover, DFX refers to its various applications, including design for manufacturing, design for logistics, and design for the environment, each focusing on a different aspect of the various X's lifecycle (Mustonen 2009).

In the electronics industry, DFX has been implemented in complex product development projects (Lehto et al. 2011; Möttönen et al. 2009) to address critical stakeholders throughout the early stages of product development, which has proven to be effective. DFX has been identified as a viable way of enhancing communication and creating capabilities for achieving competitive objectives in various industries (Halttula et al. 2017). The concept of DFX has developed over the past few decades to encompass various aspects, tools, and methodologies. This evolution has broadened the scope of DfX

beyond the initial product scope to include system and eco-system perspectives (Chiu and Kremer 2011).

2.3 Design for Environment - a part of Design for X

Increasing concerns about environmental degradation have prompted a range of studies to produce products that are more sustainable and environmentally friendly. The environmental impact of a product throughout its lifecycle is mainly influenced by the decisions made during the design process, which has resulted in the development of a number of designs for the environment (DFE) technologies. There is no one metric for environmental impact, with various stages of the life of a product influencing the environment in a variety of ways at different points in time. DFE is a subset of a family of environmentally sensitive design approaches that include design for disassembly, design for recycling, design for end-of-life, and sustainable design. (Holt and Barnes 2010)

Research into Design For 'tools and techniques' (DFX) has been conducted for decades, which offers an ideal foundation for developing the Design for Environment (DFE) approach. Design for the Environment refers to the fact that the "environment" contributes to decision-making during the design of the product. In other words, environmental considerations are taken into account during the product development process. Environmental considerations are given equal weight when going through this process with more traditional product requirements such as profit, performance, attractiveness, ergonomics, image, and overall quality. In each stage of the product development process, DFE considers environmental issues, intending to achieve products that have the least environmental impact over their entire lifetime. (Rose 2000)

Design for Environment is the systematic assessment of design performance concerning environmental health and safety objectives throughout the product and process life cycle (Kuo et al. 2001; Lenox et al. 2000; Mathur 2007; Rose 2000). Design for Environment is an essential component of the Design for X concept. It encompasses all life cycle stages, including extraction of raw materials, manufacturing, transportation, use, and end-of-life phases (Rose 2000). The scope of DFE includes environmental management, product safety, occupational health and safety, prevention of pollution, ecosystem, conserve natural resources, prevention of accidents, and waste management, with a particular

emphasis on product development (Glazerbrook et al. 2000; Mathur 2007; Ufford and Ward 1999). In general, "DFE" encompasses any design effort that tries to enhance the product's functions in the sense of environmental performance. DfE may be implemented through the use of a variety of tools and methodologies that have been created. This category includes everything from generic to specialized tools focused on particular product lifecycle stages or specific types of products or services. Others are intended for use throughout the detailed design phase, while some are used during the decision support phase early in the design process (Hauschild et al. 2004; Mathur 2007).

Design for Environment is concerned with understanding the life cycle of a product and its impact on the environment at each stage of its life cycle, as well as making better decisions during the product design process to ensure that environmental aspects of the product remain at the desired level throughout its life cycle (Rose 2000). It is essential to incorporate design for environment into the product development process early on to ensure that the environmental impacts of a product's life cycle are considered before any manufacturing choices are made. The product's performance also has an impact on the environmental implications of the product, which is something that is committed very early in the product design process. When considering the environmental consequences of a product, one should consider the many forms of pollution that it may cause, such as energy consumption, depletion of natural resources, liquid discharges, gaseous emissions, and solid waste generation. A large portion of the potential product end-of-life costs is committed at the conceptual design stage of the product development process. When designing, the goal is to offer as much important information to the designer as early as possible. As a result of the internal and external pressures for environmentally responsible design, DFE should be a component of the product development and production cycle from the beginning (Holt and Barnes 2010; Junning et al. 2003; Rose 2000; Ulrich and Eppinger 2011).

Design for Environment is concerned with understanding the life cycle of a product and its impact on the environment at each stage of its life cycle, as well as making better decisions during the product design process to ensure that environmental aspects of the product remain at a desired level throughout its life cycle (Rose 2000). It is essential to incorporate design for the environment into the product development process early on in order to ensure that the environmental impacts of a product's life cycle are considered before any manufacturing choices are made. The product's performance also has an

impact on the environmental implications of the product, which is something that is committed very early in the product design process. When considering the environmental consequences of a product, one should consider the many forms of pollution that it may cause, such as energy consumption, depletion of natural resources, liquid discharges, gaseous emissions, and solid waste generation. A large portion of the potential product end-of-life costs is committed at the conceptual design stage of the product development process. When designing, the goal is to offer as much important information to the designer as early as possible in the process. As a result of the internal and external pressures for environmentally responsible design, DFE should be a component of the product development and production cycle from the beginning (Holt and Barnes 2010; Junning et al. 2003; Rose 2000; Ulrich and Eppinger 2011).

2.3.1 Life cycle perspectives

The life cycle perspective is the cornerstone of DFE that concentrates on the manufacturing and distribution of products in a closed-loop system and links the product life cycle to that of the natural life cycle (See Figure 5). The life cycle begins with the extraction and processing of raw materials from natural resources and continues with the product's production, distribution, and use. Ultimately, at the end of the product's useful life, there are various recovery options, such as component remanufacturing or reuse, material recycling, or incineration or disposal in a landfill. On the other hand, the natural life cycle is a continuous cycle that reflects the growth and destruction of organic substances. As seen in Figure 6, the two life cycles intersect with the use of natural materials in industrial products and the reintegration of organic materials into the natural cycle. (Ulrich and Eppinger 2011).

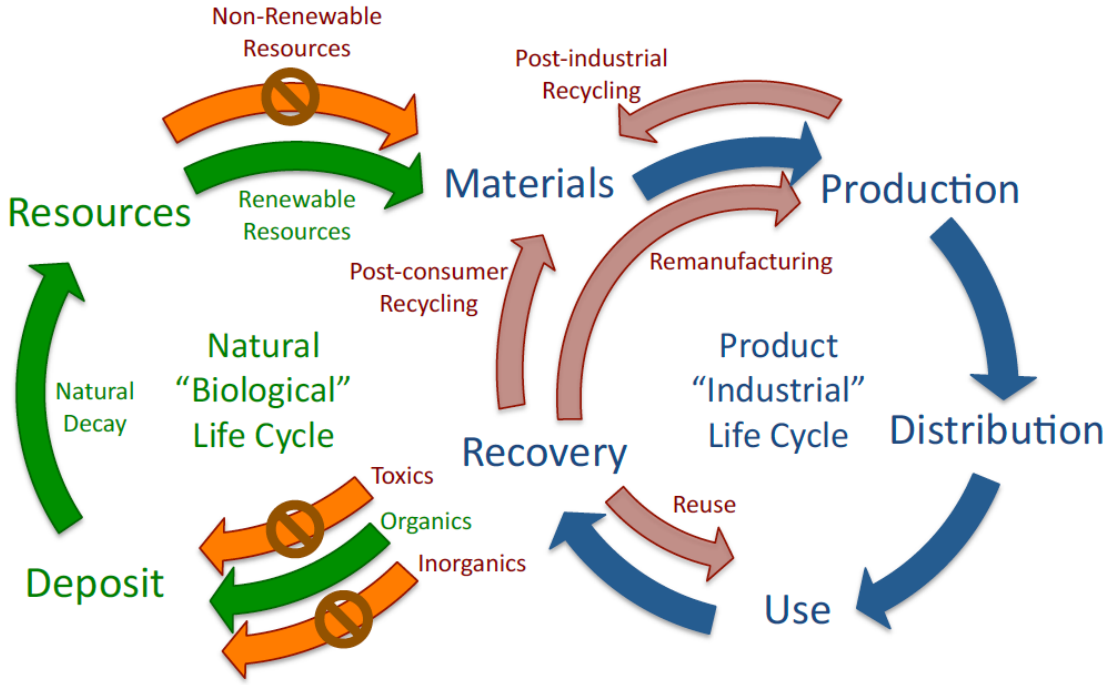

Figure 6. The natural life cycle and the product life cycle – two life cycle perspectives (adapted from Ulrich and Eppinger 2011)

2.3.2 Design for environment and sustainability capability creation

Design for Excellence (DFX) is a set of concepts, tools, and procedures used to ensure that the most cost-effective and efficient design process is carried out at all times. During the design phase of the DFX activity, all requirements of the key stakeholders are considered, with X representing each key stakeholder in the process. The DFX method has addressed numerous significant Xs in product development, such as design for the environment. DFX has been identified as a possible tool for enhancing communication and enabling capabilities (Lehto et al. 2011). The main goals of capability creation are to improve product design and facilitate efficient production (Tolonen et al. 2017). The capabilities differ as the key 'Xs" differ in DFX consideration. However, the capability creation process runs parallel to the product development process (Tolonen et al. 2017) for every Xs in DFX.

Integration of DFE into new product development ensures sustainable product design and impacts sustainable environmental performance (Suresh et al. 2016). Considering environment as a key X, the early involvement of design for environment in product design is considered integral to successful sustainability capability creation; where

sustainability is the main capability created at the end of the product development process (Gungor and Gupta 1999; Hauschild et al. 2004; Holt and Barnes 2010; Junning et al. 2003; Kuo et al. 2001; Kurk and Eagan 2008). Therefore, integrating environmental aspects for decision-making during DFE consideration is critical in the product development process as it enhances product competitiveness through sustainability creation (Choi et al. 2008).

Figure 7 shows that the effort to be made for DFE or the activities related to design for environment is high at the early phase of the product development process. At the beginning of the project, no capabilities are yet created, and the focus is more on implementing design parameters into the product (Tolonen et al. 2017). Different environmental aspects need to be considered at the beginning of the product development process, such as identifying environmental stakeholders, classifying the stakeholders, analysing and prioritizing environmental requirements, etc. As the product development process progresses, the activities of sustainability capability creation focus on the creation of sustainability capability itself. By the end of the development process, the effort to be made for the DFE approach ultimately minimises.

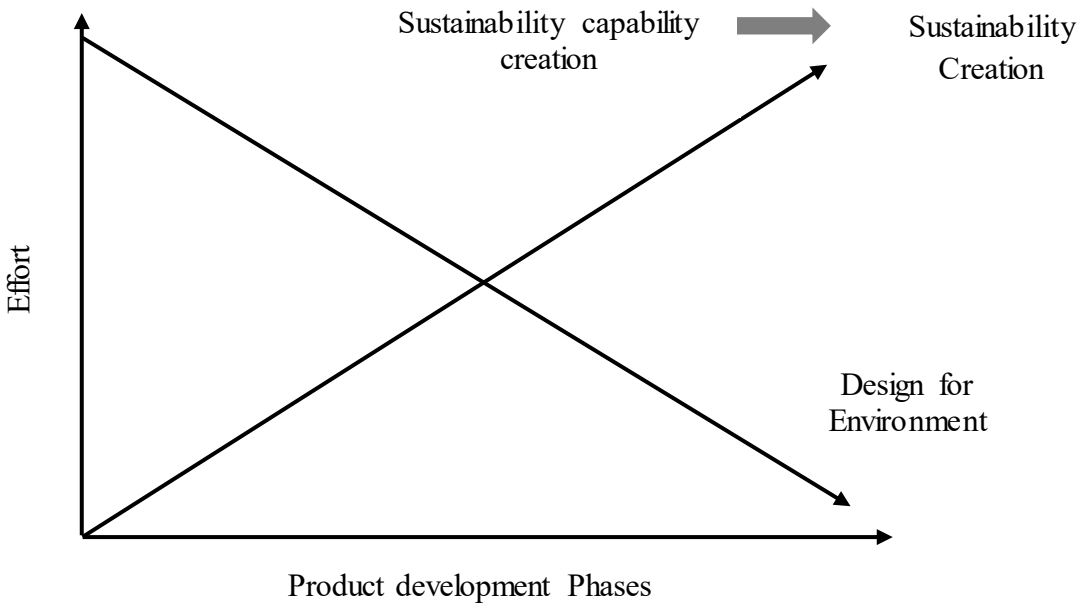

Figure 7. Focus areas of sustainability capability creation (modified from Tolonen et al. 2017)

2.4 Synthesis

DFE is a product development approach that seeks to enhance a product's environmental attributes throughout its lifecycle. The ultimate objective is to meet sustainability goals, and design for the environment facilitates product development in creating sustainability capabilities.

Sustainability capability creation and design for environment can be considered as a counterpart processes where both support each other in a loop of cycle (see figure 8). They both require and utilize identifying and analysing the key environmental stakeholders during the product development process that concerns the sustainable development. The main idea of DFE is to identify key environmental stakeholders and analysing the environmental requirements of those stakeholders and integrate those during product design. As the product development proceeds, the creation of sustainability increases. Sustainable capability creation process can be a continuous source of sustainable information that is used during design for environment implementation.

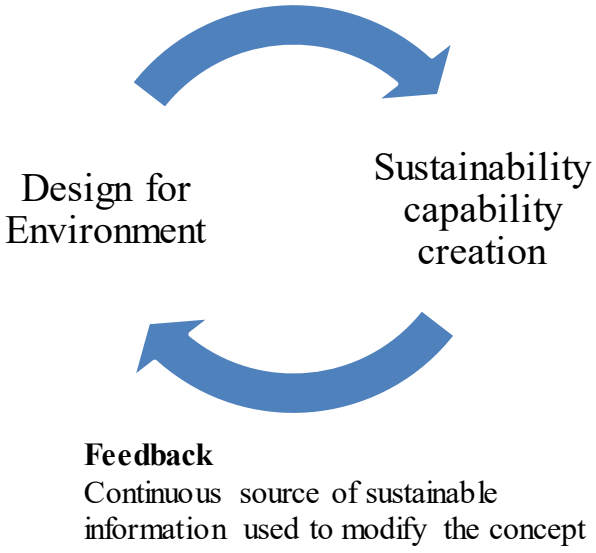

Figure 8. DFE and sustainability capability creation cycle

The sustainability capability creation process focuses on the design for environment (DFE) product design aspects, perspectives, targets, and related activities and responsibilities during the initial product ideation and conceptual phase. At the end of the

product development process, the sustainability capability creation process focuses on managing new sustainable products to be launched on the market.

Design for environment and sustainable design of electronics products is driven by sustainability thinking, customer demands, legislation, and need for appropriate use of environmentally friendly materials and ultimately penetrate the market opportunities. Therefore, it is necessary for the design team to design electronic products that are beneficial for the environment and society. This can be accomplished by analysing the actual demands and targets and then looking for a more sustainable solution that is beneficial to environment and people, supported by the use of sustainable materials, improving energy efficiency in the production, use, and distribution phases, designing products with material that can be reused and recycled after their end-of-life stage. A general guideline on DFE strategies based on lifecycle perspectives can be summarized in Table 1.

Table 1. Key DFE strategies and proposed guidelines to be considered during the product development process

DFE strategies	**Guidelines**
Design for recycle	Use recyclable parts and materials. Use of materials that can be recycled easily and that are environmentally friendly. Emphasize on using renewable materials and reduce using plastics as much as possible
Design for re-use	Use durable materials in the product so that the product can lasts long and can be reused instead of disposing completely.
Design for disposal	Avoid using harmful and toxic substances and materials
Design for energy optimization	Use materials that content low energy content

The ultimate goal of design for environment implementation in product development is sustainability creation or sustainable capabilities creation. In order to map the sustainable capabilities creation into the lifecycle of the product, a three-way view of sustainability creation based on sustainability strategy can be considered, as shown in Figure 9. At first, the sustainability targets should be identified throughout the product's life cycle, from idea generation to product design to production, distribution, use, and the end-of-life

stage. In addition, the information and feedback from the customers required for the design are included. Secondly, the sustainable targets should be identified from the perspectives of different environmental stakeholders that are related to the design of sustainable products. They can be customers, design team, suppliers, partners, competitors, etc. Moreover, finally, the sustainability targets can be characterised into several aspects and requirements on products, including product features, materials, and components used in the product, energy usage and consumption, environmental legislation and regulations, energy optimization, and sustainable thinking.

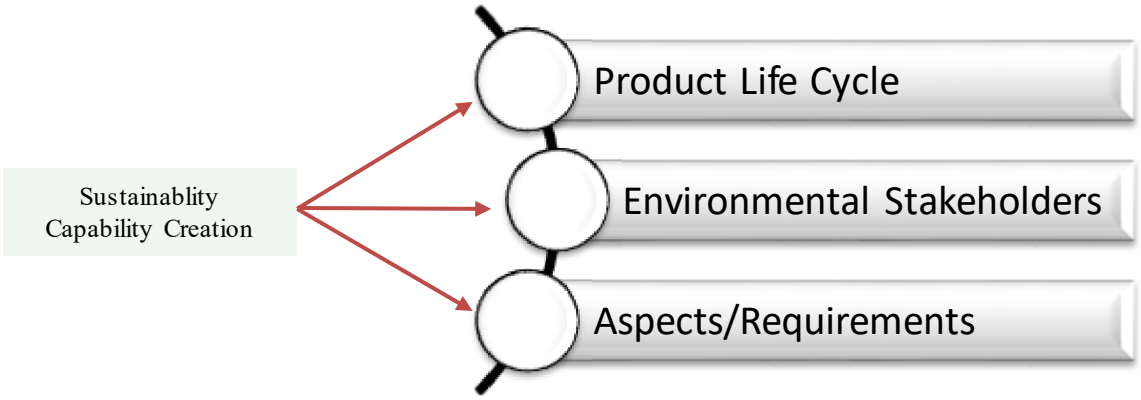

Figure 9. A three-way viewpoint of sustainability capability creation

An overview of DFX activities has been presented in this work. The issues related to environmental perspectives that should be implemented during the new product development process are described in further chapters. The basic principles of sustainable product design, including lifecycle thinking, sustainability targets, identifying stakeholders, analysing all different requirements and criteria, and prioritizing them correctly, are pointed out and described in this study.

3 METHODOLOGY

3.1 Description of research process

This chapter discusses the rationale for the selection of the qualitative research method that was used in the study, as well as a more detailed description of how qualitative research interviews are conducted in practice. In chapter 3 and 4, the empirical study process and results are presented to gain the practical insights to design for environment approaches. In chapter 5, the findings from both the theoretical research and the empirical study are combined to undertake a detailed discussion of the concepts and to provide further suggestions for effective implementation. The contribution and evaluation of the research are concluded in chapter 6 along with suggestions for further research. The research process is shown in Figure 10.

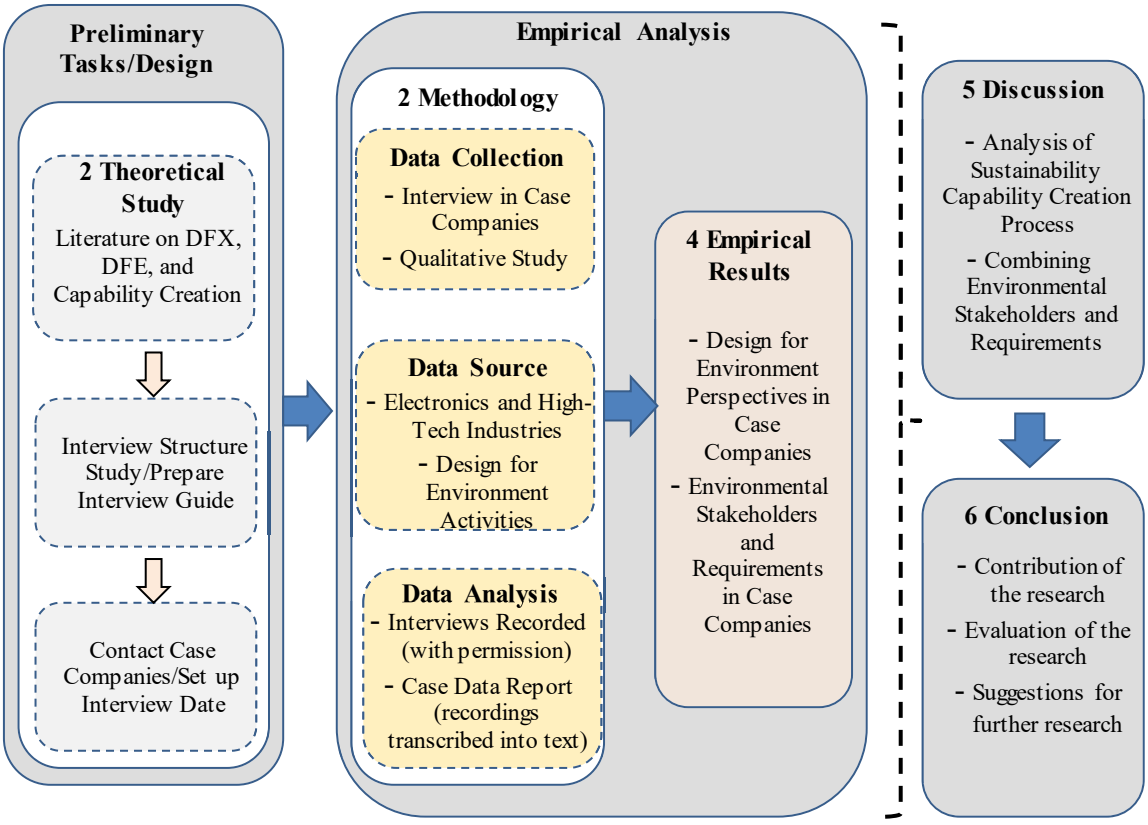

Figure 10. Research process for current study

3.2 Research design and strategy

The research addresses integrating requirements and stakeholders at a generic level in relation to design for environment modules for future consumer electronics. The unit of analysis in the empirical research has been the companies. The data has been collected from environmental specialists or DFE experts who have a key role in defining the design for the environment approach during product development. The current research approach is justified by the research questions and unit of analysis.

The case studies are used to build a more comprehensive picture and develop a deeper understanding of the studied phenomena, which involves examining and analyzing extensive data within a specific context (Schell 1992; Zanal 2007). Case studies, according to Yin (2014), are preferred when the researcher focuses on a contemporary phenomenon within its real-time context and has limited influence over the events, as well as when multiple sources of information are accessible. Moreover, the case study research is suitable for the current thesis study as it focuses on the "how" question, which is more exploratory (Yin 2014). The thesis aims to highlight *how* the DFE stakeholders and requirements can be combined at a generic level. Since such open questions facilitate the generation of qualitative insight, a qualitative empirical study is overall more appropriate to reach the goals of this study (Saunders and Lewis 2012).

For this thesis, a qualitative study approach in a holistic multiple case study was used (Figure 11), based on the case study framework proposed by Yin (2014). A multiple case design provides a robust study with several sources of evidence through replication, where each case serves a definite purpose within the scope of the research (Zainal 2007; Yin, 2014). Similarly, by drawing on data from several sources and cases, a multiple case study provides the ability to examine similarities and dissimilarities between them, hence making the research more robust, more reliable, and valuable (Baxter & Jack 2008; Yin 2014).

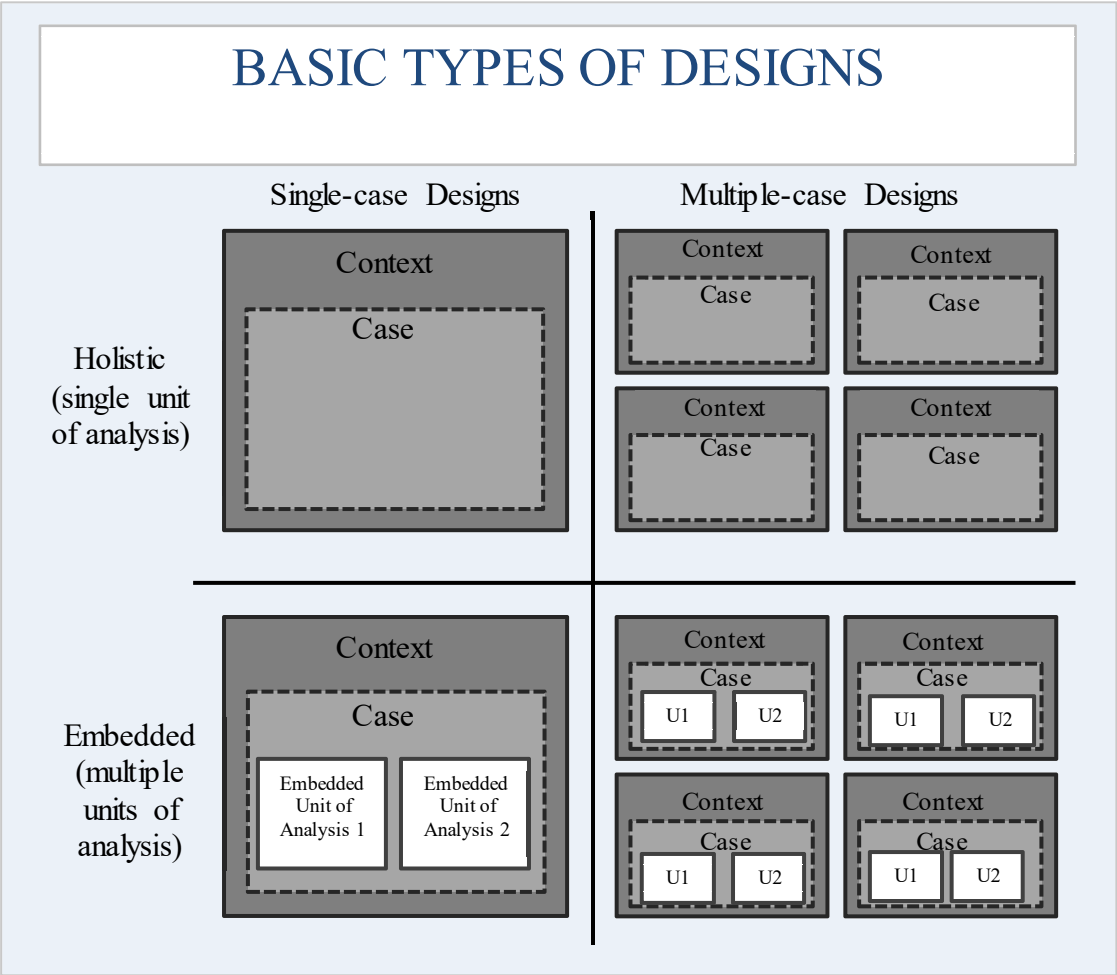

Figure 11. Basic types of case study (Yin 2014)

Furthermore, because the field of design for the environment is relatively new, it is apparent that empirical research will be required, mainly because a basis in formalized experience and knowledge must be constructed to provide findings that are practical in the industrial environment. The study was conducted using an empirical basis in the electronics industry. Since it contains knowledge about challenges and opportunities for development and improvement regarding design for environment requirements, the subjective experience of professionals in quality, design, and the environment is significant. Exploring the individual experience of environmental professionals is a method for discovering valuable outcomes in the industrial context. According to Miles and Huberman (1994), one of the benefits of gathering qualitative data through qualitative empirical research is focusing on real-life since it is based on naturally occurring phenomena. As a consequence, it aims to provide industrially relevant results.

3.3 Data collection

The objective of the empirical aspect of this study is to obtain a general understanding of how the electronics industry approaches the concept of design for the environment in practice, as well as what the requirements and stakeholders for design for the environment are in the first instance. It was not feasible to have direct access to data; therefore, interviews had to be conducted in order to gather information. According to Yin (2014), conducting interviews is suggested since the study is concerned with current events. The primary objective is to get information about the operations and incidence of the topic under consideration. Hence, the interview approach is used in this study for data collection purposes.

Semi-structured interviews are beneficial for this type of research. They provide structure to the interview while offering a degree of flexibility and can be adjusted on the go depending on the needs of each interview session. In particular, semi-structured interviews allow to exclude questions from the interview or add new ones depending on the replies of the respondents, which can be helpful since the answers from the participants can be complicated and unpredictable (Saunders & Lewis, 2012).

Semi-structured interviews were conducted with the environment specialists and experts in the electronics industries. A semi-structured interview guide (see Appendix 1) was created based on the outlined theoretical framework and previous research on this topic. The interviewees received information about the study in advance via email to make sure that the goals of the study were clear to them. The interview guide was provided to the interviewees before the interview, allowing them to think about the questions before the interview. The interview lasted for 30 minutes and an hour. Because of the present COVID-19 situations, face-to-face interviews were not conducted; thus, the interviews were performed using the Teams Meeting platform. However, the interview conducted through Teams Meeting let the interviewees convey their ideas and knowledge more diversely and appropriately. In addition, it provided the interviewer with the opportunity to ask further questions on the topic and related concerns. During the interviews, replies were promptly interpreted to ensure that the interviewer received the correct meaning of the responses. Thus, during the interviews, the researcher was able to learn more about the subject in depth.

3.4 Data sources

The primary source of data for this study is semi-structured interviews targeted at electronics industries in Finland. Along with interviews, the information was collected from the company websites and the company's sustainability report as a primary data source. The companies were selected based on personal contacts, and they were approached through email to inquire about the possibilities of interviewing at a time convenient for them. In addition, this research also relies on several other data sources, such as available research articles and reports, as secondary data. The variety of versatile data sources and analysed material enabled to enrich and triangulate emerging insights and transparently validate the findings. The overview of the interviewed companies is listed in Table 2.

Table 2. List of interviewed companies

	Industry/Sector	**Size**	**Interviewee(s)**
Company A	Telecommunication, information technology and consumer electronics	Large	DFE Experts
Company B	High tech industry, producer of high strength steels	Large	Director for Environment and Safety
Company C	Sports training computer/equipment	Large	Director of Quality, Quality Specialist, Line Manager (Creative Design), Specialist (Mechanical Development), Specialist (Product Approval), Senior Industrial Designer

The study involved an in-depth analysis and study within a specific field aiming to gather a maximum of first-hand information about the studied phenomenon at the company, including design for X, environment, design for environment, environmental requirements and stakeholders, and design for environment challenges and importance.

3.5 Data analysis

The nature of this research study was qualitative, and no quantitative data were used; the study utilised qualitative methods to analyse the data. The analysis is done in a few steps. The data collected through interviews were at first transcribed into text. After that, the themes were constructed based on the literature review and the interviews. The themes were then refined to make the themes more concrete and specific, which helped to provide a structured overview of the relevant data. Next, the main insights from the interview were distilled and presented clearly in the results section without any analysis and changes. The results were then analysed and discussed, and finally, the conclusions were provided for the central questions of this study.

4 CURRENT STATE ANALYSIS OF DESIGN FOR ENVIRONMENT IN ELECTRONICS INDUSTRY

4.1 Sustainability approach in the studied companies

4.1.1 Sustainability goals and focus areas

Sustainability is the core and integral part of the strategy and the design of the products in every interviewed company. The companies see sustainability not just as the money but refer it as serving to their customers and at the same time making sure that they do the things (make products and services) in the proper way. The companies have their core focus areas where they have the most significant impact. Table 3 presents the different focus areas of the interviewed companies along with their sustainable goals.

Table 3. Overview of sustainable goals and the key focus areas of the studied companies

	Focus areas	**Sustainablity goals**
Company A	Climate	- Solution-based approaches to combating climate change, including mitigation and adaptation strategies. - Reduce emissions and achieve climate goals by taking use of the enabling effects of digitalization and new technology.
	Integrity	- Emphasising the significance of respect for ethical behaviour, as well as for security and privacy. - Engage in ethical and transparent business practices with employees, suppliers, business partners, consumers, and other external parties in order to maintain mutual respect.
	Culture	- Assuring the flexibility to attract the best individuals and building high-performance diverse teams that make things happen. - Develop not just the culture, but also talent management activities, performance assistance, and career development on a continuous basis.
	Environment	- Reduce carbon footprint with low CO_2 steel - Reduce CO_2 emissions in the use phase - Be the first to provide fossil-free products - Minimizing environmental impact through the efficient use of raw materials and energy
	Safety	- Becoming the world's safest steel company

Company B	Respect and Integrity	- Zero tolerance for bribery and corruption - Provide equal employment opportunities for all employees regardless of their age, gender, ethnic background, physical ability, political and religious beliefs, or any other attributes. - Boosting women's involvement in senior management positions. - Aim for inclusion to guarantee full and equal participation of everyone representing whole range of diversity within the organization.
Company C	Climate	- Make transition towards a carbon-neutral future
	Environment	- Consider the environmental implications and impacts of products throughout their life cycle, from creation and production through delivery and customer service. - Develop materials and manufacturing process and methods on a continuous basis in order to eliminate scrap and waste. - Manufacture products using materials that are safe for environment.
	Human Rights	- Focus on protecting human rights throughout all the operations and activities and regularly assess the impact of its operation on human rights in order to reduce and eliminate any risks that might occur. - Prohibit the use of child labour or forced labour across its operations. - Provide employees with the benefits that are required by law and guarantee that they are working in a safe environment. - Support equal employment opportunities. - Provide a work environment where all the individuals are treated with dignity and respect.

4.1.2 Sustainability strategic approach

The objective of all companies is to deliver more sustainable products and work toward creating a better, cleaner, and more sustainable world, thereby providing social and environmental benefits for individuals, industries, and society in general. However, Company A and Company B have different strategic approaches to sustainability to make their businesses more sustainable. In contrast, company C does not have any specific sustainability approach but aims to develop sustainable products.

Company *A*

The sustainability strategy approach is the outcome of an in-depth analysis of their sustainability activities, requirements, and achievements, emphasizing impact, scope, focus areas, and targets. The strategic approach to sustainability is based on several factors relating to business and its implications for sustainable development, including global macro trends affecting sustainable development, consistent interaction with various stakeholders, customer and investor requirements and information, and performance metrics of industry peers and sustainability leaders, and analysis of sustainable value throughout the value chain. Figure 12 represents the strategic approach to sustainability for company A.

Figure 12. Strategic approach to sustainability of Company A

Company *B*

Sustainable development is a critical business driver for both the company and its consumers. As a result, the company puts much effort into ensuring that it operates ethically and environmentally responsible in its activities and markets. The company's sustainable strategy is termed "With the Future in Mind" (Figure 13), and it consists of two key themes: first in fossil-free steel and leading sustainability performance.

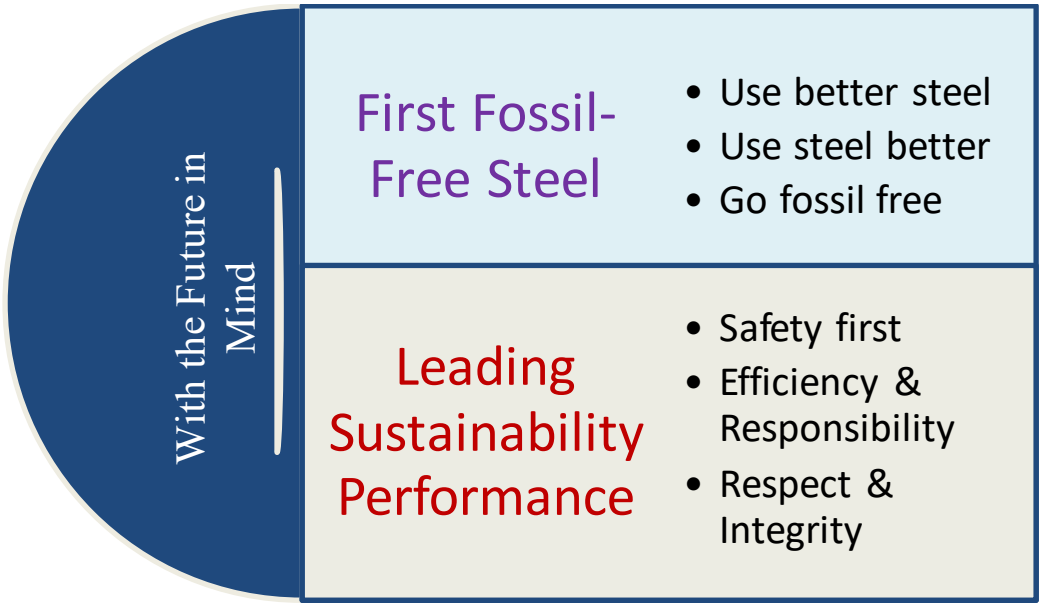

Figure 13. Sustainability strategy of company B

Company *C*

Company C is devoted to improving the globe by helping customers improve their health and well-being and continuously enhancing its products and operations to become more sustainable. Company C does not have a particular sustainability strategy. However, it focuses on creating long-lasting products, recycling and collecting old products, and recycling packaging material globally per local regulatory requirements.

4.2 DFX approach in the studied companies

DFX is present in every company. DFX is implemented into the early phase of the product development process in every company. In Company A, the DFX concept has been used for many years. DFX as a concept is utilized in many areas throughout the company in terms of reliability, quality, manufacturing, security, and the environment. DFX is a part of a broader program for the design community. Many DFX attributes start to come into play from the early stage of product development activities. Company B has 'design for manufacturing' as a discrete activity in the early conceptual phase of the product development process. In company C, DFX as a concept has been used in different aspects, such as design for manufacturing and design for assembly.

Table 4. Overview of DFX attitudes in the studied companies

	Attitudes towards DFX
Company A	- DFX is a part of a broader program for the design community - DFX integrated from early phase of product development - DFX as concept utilised - DFX used in many areas throughout the entire company in different aspects such as reliability, quality, manufacturing, security, environment.
Company B	- DFX is integrated into early phase of product development process - Design for manufacturing is used at early phase of product development process
Company C	- DFX as a concept is used in different aspects such as manufacturing, assembly.

4.3 Design for Environment (DFE) concepts in the studied companies

Every company considers the environmental aspects of its products during product development activities. All companies aim for sustainable development, and all of them have their requirements and practices set to achieve the environmental objectives throughout the product development process. However, only Company A utilizes DFE as a separate concept to control and set the objectives to avoid environmental harm. Company A has a DFE program, which is a set of documentation that sets both requirements and guidance for the design community, and that comes with the checklists that are part of the development gate process. In contrast, Company B and Company C do not have DFE concepts, but they include environmental issues as an essential aspect of their product development activities. Table 5 summarizes the approach to the DFE concept at the studied companies.

Table 5. DFE utilization in the studied companies

	DFE as a separate concept
Company A	- DFE is used as a separate concept - It utilizes a DFE program where requirements and guidance are set for the design community - DFE is integrated at the early phase of the product development process - DFE experts are involved in reviewing and considering the requirements, guidance, checklists, and finalizing the design considerations
Company B	- DFE as a separate concept is not used - Environmental aspects and issues are considered throughout the product development process - Doesn't have specific DFE experts but they have experts who follows all the safety, legislation, and requirements and environmental and social aspects.
Company C	- DFE as a concept is not utilized - Environmental issues are included in the early stages of new product development and material supplier selection - Doesn't have specific DFE or environmental experts - Quality team from IT, mechanics, electronics, work together and consider the environmental aspects in the design of the product.

4.3.1 Perspectives on environment

The way the company perceives the environment determines how it approaches problems. Every company has its perspective on environmental performance to achieve sustainability. Every company interviewed aims to improve the environmental performance of their products. Companies have included environmental targets in their product development activities, and significant efforts have been made to create environmentally friendly products. Table 6 presents the company's perspectives on the environment.

Table 6. Perspective on environment at the studied company

	Perceptions on environment
Company A	- All the aspects of the product that have an impact on the environment - Physical stream – turning into a chain of cycle rather than just a one way throughout – a concept of reuse, recycle and recover options. - Energy use by the product – the energy use during the product usage usually lists the environmental impacts and that should be addressed. Try to evolve in the technology on reducing the energy use - If looked at the organization as partly separate issues, it goes more into supply chain management, but in terms of sustainability, those all come together - So, the environment can be seen as a separate thing or just one thing within the sustainability concept.
Company B	- Environment is a part of the sustainability strategy - When comes to environment, it means CO_2 reduction - Continuous improvement to minimize emissions and improve productivity - The types of material used and material flow to the customers enabling reducing the environmental footprint - Forming a fossil-free value chain
Company C	- Considering the overall impact of the product and its environmental aspects throughout the life cycle of the product - Environmental issues are included in the early phase of material supplier selection - Supply chain management from key materials to retailers – ensuring the environmental aspects - Have to follow the environmental and regulatory compliances – because the products are sold globally, those kinds of regulations have to be considered in a global view as well.

4.3.2 Environmental requirements

Product design and development require consideration of several aspects. Different kinds of requirements from different stakeholders need to be considered and utilized during the product development process. There are customer requirements, material selection requirements, legal requirements, etc., that must be taken into account during the early phase of product development. Four major kinds of requirements were realized from the interviews, which are briefly discussed in this section.

Material and energy requirements

Material and energy are the major aspects that the companies try to minimize in their use in their products. When looking at the requirements, the company looks at the

environmental aspects, what materials go into the product, and what materials need to be substituted or avoided to have the minimum impact on the environment. For example, Company A uses high recycled materials. By doing so, they are avoiding the impact to the environment, not only on global warming potential but also on resource depletion. So, they look at the eco-aspects that are of the company's highest significance and have the most impact on the environment. At the same time, they try to minimize energy usage during the production and distribution of the products.

Similarly, Company B focuses on continuous improvements in order to reduce emissions while increasing productivity and material and energy efficiency. They focus and work towards making fossil-free steel so that their customers can produce sustainable products that reduce their environmental footprint. At Company B, the energy flows throughout the production process are recycled to improve energy efficiency. Company C focuses on environmentally usable products. They try to use recycled materials in their products and consider the environmental aspects wherever possible. At the same time, they emphasize making durable and functional products that last longer. Thus, the material selection bar is at a high place.

Legal requirements

Legal requirements are hard requirements that all companies have to fulfil. They do not have any option other than to follow the laws and regulations. The legal requirements fall under the most critical requirements for all companies because they cannot sell the products if they do not follow the regulatory requirements. Environmental regulation is a dynamic process, and the regulations keep changing. Thus, the companies constantly follow the updates and keep track of what kinds of materials are used in their products. For instance, Company A tries to avoid using the materials or substances that will be banned in five years so that they do not have to redesign the product and make sure that the product they develop meets the requirements in the future. So, the legal requirements come as an absolute.

Similarly, it is crucial for Company B to follow the environmental permits, for example, how much CO_2 can be emitted and how much dust and fumes can be emitted. They need to obey all these regulations and try to improve all the time. For Company B, the European Union Emissions Grading System is the most important environmental legislation.

Likewise, Company C follows the environmental standards that impost on the usage of certain materials in their products. In addition, they regularly look forward to developing the product so they can sell it in the future.

Customer requirements

The products are made for the customers, and their needs and demands have to be fulfilled. The customer's requirements are essential for the business; however, the company can still negotiate to a certain degree. Nevertheless, customer demands are increasing, and the company is considering it carefully. For example, the construction industry and the automotive industry are the biggest customers for Company B, and they both have very strict requirements for the product. The product cannot contain anything that can be harmful to people or the environment. So, they need to consider this during the product development and ensure that they do not have any hazardous substances or materials in their product. The company must make sure that they help their customers do good and sustainable business, thus adding value to their customers and strengthening the relationships with their customers.

Voluntary requirements

Voluntary requirements are categorized by Company A as their last category of environmental requirements. These kinds of requirements would be those things that the company thinks are good for the world. For example, they try to avoid using substances that would make it impossible to use recycled plastic. So, these kinds of requirements are flexible, and the company has the option to prioritize them as per their needs and situations.

Table 7. Environmental requirements in studied companies

	Environmental Requirements	Descriptions
Company A	1. Material and Energy requirements	- First look at the environmental aspects - Follow ISO 14000 in classifying environmental aspects - Try to change or avoid and substitute materials that have high environmental impact - Use highly recycled materials - Try to minimize materials and energy in the use in the products - try to minimise energy consumption
	2. Legal requirements	- These are hard requirements. No negotiations. - Consider the requirements in today and in the future. - Avoid using certain substances what will be banned in five years, for instance. - Make sure to develop the product that meets the legal requirements in the future.
	3. Customer requirements	- Listen to the customers' requirements - Customer requirements regarding material selection, avoiding certain material - Can still negotiate to a certain degree
	4. Voluntary requirements	- Those things that are good for the world - For example, try to avoid those substance that would make it impossible to use recycled plastic
Company B	1. Legal requirements	- Environmental permits, for instance, how much fumes and dust, and sulphur can be emitted. Need to obey these regulations - From business perspectives, European Union Emission grading system is the most important environmental legislation - Should have global solutions and global efforts to mitigate the climate change
	2. Customer requirements	- Enquiries from customers are increasing - Customer requirements regarding chemical content of the product and the possible hazardous element that the product can content - Construction business and automotive business are the two big customers. They have strict requirements for the product. The product cannot contain anything which can be harmful for the people and the environment
	3. Material and energy requirements	- Focuses on continual improvement in order to reduce emissions while simultaneously improving productivity and material and energy efficiency

		- Customers are able to produce lighter and stronger products, resulting in a reduction in their environmental footprint - Works toward a fossil-free steel making process - Develop a fossil-free value chain with supplier and energy provider - Energy flows are recycled in the production process in order to improve the energy efficiency.
Company C	1. Legal/Regulatory requirements	- Most important requirements, because if those legal requirements are not followed, then the products cannot be sold in the market. - Follow the standards - Since the products are sold globally, have to consider the regulations in the global view as well - Environmental regulations – it's a dynamic process. Constantly follow up the updates. Those environmental regulations keep updating and keep track on what kind of materials are used in the products and so on. Need to know all the time what substances are allowed and what are not. - When developing product, have to look forward in the future, because those are evolving all the time.
	2. Customer requirements	- There are a lot of electronics inside the products and the requirements in the product like water resistance, outdoor conditions are very demanding
	3. Material requirements	- Focus on environment usable products - Take into account the environmental aspects wherever it's possible – trying to choose the ecological options and environmentally sustainable options - Sets the bar for the material

4.3.3 Environmental stakeholders

The complications of environmental concerns demand the need for the design team to conduct research, engage stakeholders, and get information from them. Stakeholders have information that may benefit the product life cycle design process, which is essential for developing environmentally friendly products. There are stakeholders actively participating in product development that is primarily based within the company. Other stakeholders are not directly involved in the product development process but significantly impact producing sustainable products; suppliers, customers, investors, peers/competitors. Figure 14 shows a simple model of a network of stakeholders around the product development at interviewed companies.

Business groups

Business groups directly influence the product development process at Company A. They are making products and providing as a point to sell products or as a service. Throughout the company, there is a flow of communication with the business groups. They can have control from the central standpoint or design for environment requirements, guidelines, best practices, tools, etc.

Quality team/experts/product design team

Anything related to the design of the product is a stakeholder. For Company A, they are the product design team that designs the product and directly relates to product development. The product is designed and developed according to the requirements. At Company B, they are experts, or the people responsible for making sure that they follow all the safety, legislation, and requirements and other people who follow the environmental and social aspects. So, they have roles inside the company, and those experts help the organization fulfill what is expected and what is needed. At Company C, they are the quality team as a stakeholder who considers the environmental aspects of the product design. The quality team consists of people from different departments such as IT, mechanical, electronics. They work together for selection, ideation, development of the product throughout the entire product life cycle.

Customers

Customers are one of the most important environmental stakeholders for all of the interviewed companies. The needs and requirements of the customers are realized at an early phase of the product development process, and the company uses this information for concept creation and the design of the product. Customers are an important stakeholder for Company A because they buy the products and services. The company wants to know from their customers what their needs are and what requirements the company needs to meet from the customers and their end-users. So, all of that information from the customers gets rolled together in getting input for the product design and creation, and DFE experts track the input changes. The big customers for Company B are the construction and automotive businesses. Both customers have very strict requirements for the products that they cannot contain anything that can be harmful to the people and the environment. Inquiries from customers are increasing all the time, for example,

regarding the chemical content of the product and the possible hazardous elements that it may contain. So, the company needs to consider this during product development, try to create a product with new features and qualities, and assure that the company does not need to add any hazardous substances. The company must make sure that they help their customers do good and sustainable business. By doing that, they add value to their customers and strengthen customer relationships. Thus, customers are the main stakeholders for Company B.

Supply chain/suppliers

The supply chain comes in the first place for Company A because they have a very deep supply chain with many tiers, and they interact with them. For example, Tier 1 is involved mainly in directly buying parts from the suppliers in the sub-assemblies. They work with them to make sure that they are looking at environment and sustainability the same way the company is looking at, and they are under ISO 14000, etc., and doing things with continual improvement. And then they get into other tiers to some extent. For instance, they have to track down a source of material, so they need to know where the sourcing of certain materials comes from. So, that gets deep into the supply chain, and thus they are an important stakeholder. Similarly, for Company C, in the sourcing phase, when selecting the materials, the supplier is the main stakeholder.

Investors/investment community

Investors or investment community are considered as a stakeholder for Company A that invest in the company in different ways. The investment community gets all the information regarding the carbon footprint, or any input changes through the company's annual report. They want to either produce products, invest in products or want to directly buy the stock. Company B and Company C didn't particularly highlight the investor as their prime stakeholders.

Peers in the industry

Peers in the whole electronics industry are the stakeholder for Company A as they are working in a trade association. They are one of the companies that buy components from suppliers or individual power is not extreme. Company A are cooperating in a certain number of aspects with their peers in the industry to address certain kinds of issues and

to have electronics product manufacturers towards their supply chain and to make changes together. Thus, Company A considers peers in the industry as their stakeholder.

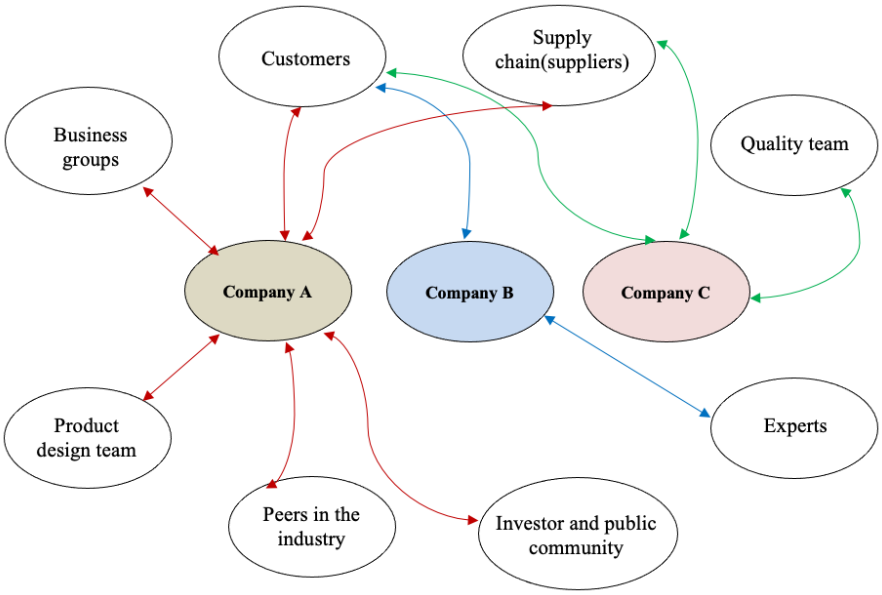

Figure 14. A model of network of environmental stakeholders around product development process at the interviewed companies. The two-way arrows indicate the flow of communication regarding the environmental aspects at the companies.

4.3.4 Environmental stakeholder (ES) classification

Special frameworks or methods are not used for prioritizing or categorizing the environmental stakeholders at neither of the companies interviewed. The companies recognize the stakeholders as internal vs. external stakeholders. Internally, they are within the company. They are the experts or the product design team, or the quality team involved in designing the product and who take care of the environmental requirements. So, they control and manage the design for environment requirements, guidelines, practices, and tools throughout the product life cycle. For Company A, the internal stakeholders are the business groups and the product design team who design the product and have a direct connection with the product development process. They are the experts at Company B who are responsible for ensuring that all safety, legislative, and regulatory standards are met and for complying with environmental and social responsibilities. At Company C, the internal stakeholders are the quality team responsible for taking care of the environmental aspects during the product design.

Externally, they are outside the company but have direct connections with the product and its usage. The external stakeholders recognized from the interviewed company are the supply chain or the suppliers, customers, investors, and peers in the industry. For Company A, the external stakeholders are the supply chain, customers, investment community, and peers in the industry. For Company B, customers are the most important environmental stakeholders. Similarly, they are the suppliers and customers for Company C.

Table 8. Environmental stakeholders in studied companies

Interviewed Company	**Environmental Stakeholders**	
	Internal Stakeholders	**External Stakeholders**
Company A	1. Business Groups - That are making products and in providing them either as a point to sell products or as a service - They can control and ask from central standpoint or use to design for environment requirements, guidelines, best practices, and tools, etc.	1. Supply Chain - Supply chain is in the first place. Work directly with them to make sure that they are looking at environment and sustainability in the same way. - Gets deep into supply chain
	2. Product Design Team - Those designing the products. They have a direct association with product development	2. Customer - They buy the products and services and company want to know from the customers what their needs are, what requirements company needs to meet from the customers.
		3. Investor and Public Community - They want to either produce products, invest in products or want to directly buy the company stock, for example. - Company publishes an annual report that gives all information as to how the company meets not only the environment but also the social aspects, and the people aspects. - Investors get all information regarding the carbon footprint
		4. Peers in the industry - Operating in a certain number of aspects with the peers in the industry (not only telecommunications industry but the whole electronics industry) to

		have electronics product manufacturers towards the company's supply chain and to make changes to help to work together.
Company B	1. Experts - People who are responsible for making sure that the company follows all the safety, legislation, and requirements. And other people who follow the environmental aspects and social aspects.	1. Customers - The most important stakeholders. - The company must make sure that they help their customers to do good and sustainable business and by doing that, they add value to their customers and strengthens the customer relationships. - The main customer segments include automotive, building construction and infrastructure, industrial applications, heavy transport (inc. marine), energy, construction machinery, and service centres.
Company C	1. Quality Team - There are people in IT, mechanics and electronics who work together for the selections, ideation, development and so throughout all the phases of the product life cycle. They are the one who take care the environmental aspects in the design of the product.	1. Suppliers - In the sourcing phase, when selecting the materials – is one of the main stakeholders 2. Customers - The customers who buy and use the products

4.3.5 Environmental requirements management during product development process

The environmental aspects of the product are considered in every company. There are systematic procedures throughout the product development process to track and manage the environmental requirements (ER) to strive for the systematic flow of product development from the initial phase until the end. At every company, coordination and communication occur between different individuals and teams so that all the departments have the knowledge and understand the requirements imposed on the product. They have constant tracking of the requirements throughout the stages of product development in every company. So, if there are any changes in the requirements during the product development process, they can track and modify the product as needed.

Table 9. Requirements management in studied companies

	Requirements Management
Company A	- Constantly checking what input is changing - There is a separate group who deals with supply chain aspects and the environmental aspects - There are people who work on understanding what requirements need to be put on the supply chain and what updates are coming about, for example, new requirements, new restrictions, etc. It could be legislative in nature or it could be voluntary that the company decided to exclude. - There is a team called customer experience that relay directly to the customers and get feedback about the products, their expectations, what they want to see in the next generation, etc. and that comes to the product design team. - Substances and materials that should not be using or want to avoid are listed in the company's substance list and is updated annually. So, whenever there is a change, that is directly communicated to the suppliers and the development community, and similarly, whole set of environmental requirements that are the part of DFE program are reviewed and updated annually. - There is a gradual change, basically, any product that is being developed, if the hard requirements change and that will have an impact on ongoing design and may even have impact on products that have been designed in the past. - It is a continuous program of updating requirements and if needed updating products.
Company B	- The requirements may change depending on the time span - Sometimes the product development can take 2-3 years and there might be some new requirements coming up and then the company must go back and see that they fulfil all the requirements. - Basically, the company knows from the start the requirements the product must fulfil and then if the legislation changes or the other requirements changes, then they must go back and do another loop and see if they need to change that the legislation is different. - There is in-house training for chemical legislation and customer requirements. - People starting from R&D to the production and to packaging and sales, all departments understand what requirements are and they know what they need to ask from suppliers who delivers the materials so that they are able to tell the suppliers what the requirements are and what the customers' demands are.
Company C	- The company established a process to keep all the relevant standards up-to-date and the company review those standards and requirements regularly. Especially, when a new project is started, all the relevant standards and requirements that have to be used and fulfilled in the coming products are reviewed. - There is list of requirements and standards which is updated twice a year. - The typical product development process from the very start until it is in the market is about 2 years. - There might be some changes, definitely. Thus, the company need to be proactive and try to understand beforehand what was coming so that they don't run into problems at some point during the product development phases.

4.3.6 Strengths and challenges

Strengths

Not all the interviewed companies have a DFE approach, but all consider the environmental aspects during product development and have sustainability targets. All of the interviewees realize different strengths of implementing the DFE approach or considering the environmental aspects during the product development process in different ways. For example, at Company A, assessing environmental aspects helps designers understand what new materials and components they are using and what new products they are planning. Company C focuses on creating a safe product so that its customers can be assured of the safety of their product.

Challenges

There were no severe problems in executing the DFE approach or implementing the environmental aspects in any of the interviewed companies. However, there are some challenges they may face in the future, or the or ones facing currently. Company A highlighted that one of the significant challenges in the electronics industry is the constant change taking place as the electronics industry is evolving rapidly and new technology is coming quickly. Company B stated that there might be issues in having control over the material. Finally, company C noted that the problems might arise due to conflicting requirements. Also, it can be difficult to constantly balance the high demands and the environmental aspects of the product.

Table 10. Summary of strengths and challenges of the DFE approach at the studied companies

	Strengths	**Challenges**
Company A	- helps in understanding what new materials and components are using., what products they are planning - early involvement of DFE approach in the design minimize the costs and reduces the number of development engineer needed for developing new product. - gives a view of what is coming ahead, what is going on and what will the	- constant change in electronics industry. Electronics industry is evolving very rapidly, new technology is coming quickly. The industry is very high-tech, that means the process that are used to make the components are highly complex. - Legal restrictions – the legal requirements seem to focus on all aspects but independent to each other. So, while the company might be adding certain substances to reduce the energy use, at the same time the substance may make a legal

	company need to adjust in coming future. - helps in meeting the sustainability targets at the end.	restriction. So, at the end of the process it may happen that the materials cannot be used because one of the substances presents is restricted.
Company B	- more safety from the product can be assured.	- There is requirement that the company should increase the amount of recycled material in the product, and then that can be a challenge. It is because when you start from virgin raw materials, or pure raw materials, you know exactly what is in there. But, when there is a requirement that you must have at least 30% of recycled material in the product, then you don't have such a control over the material anymore. So, that can be one of the biggest challenges. - can't be sure if everything is not analysed and that can be quite challenging as well.
Company C	- easy and helpful in choosing environmental materials - produce environmentally friendly product	- conflict of requirements. - There is high level of standards that the product is good, usable, durable and so on that the company have to achieve and at the same time the company have to use materials which are capable for that and then as much as possible provide environmentally friendly products but there might be a conflict. - Constant balancing between the high demand, and materials, and environmental aspects.

4.4 Synthesis

The generic environmental stakeholders and the requirements have been presented in sections 4.3.2-4.3.4. The environmental stakeholders and their requirements must be realized during the initial phase of the product development process. The ultimate goal of utilizing the DFE concept is to create sustainability capabilities, and analysing key environmental stakeholders and requirements is the cornerstone to achieving the DFE goals.

The types of DFE stakeholders are two-folded. First, from the viewpoint of power to influence the decision-making during product development, the environmental stakeholders are internal stakeholders from inside the company who actively participate in the product design and development process. Second, from the indirect participation

viewpoint, they are external stakeholders from outside the company who do not have power in decision-making but have substantial influence in the product design and development process. The key environmental stakeholders carry key environmental requirements that the company must consider in making discrete changes in the new product development process.

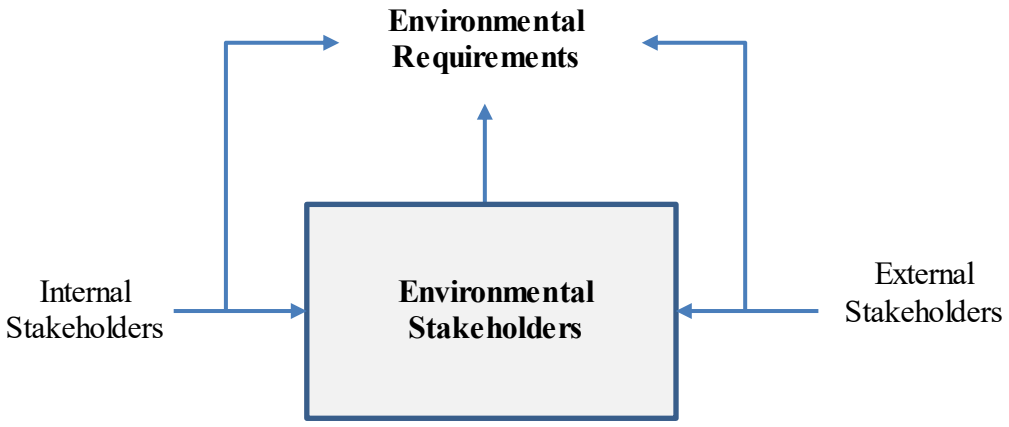

Figure 15. Design for environment stakeholders can be internal and external and carry key environmental requirements that are important for product development process

Perspectives towards design for environment

Not all the companies in this study have recognized or presented the DFE as a concept in the conceptual systems. However, the environmental aspects of the product are considered and integrated early in the product development process. This defines the key activities that drive the execution of DFE for the creation of sustainability capability.

Out of three interviewees (three companies), only one recognized the 'design for environment' concept, while the other interviewees reflected the aspects of the environment. In that sense, the design for environment is comprehended by the companies even though it is not regarded and utilized as a separate concept.

Two of the companies did not have a comprehensive view of the concept but instead perceived DFE as an environmental viewpoint to be addressed during product development. All design for environment (DFE) activities appear to have been linked to the product development process, supporting the general responses obtained in the interviews.

From the interviews, it became clear that the activities related to DFE or simply environmental aspects during the product development process are considered very essential. The DFE process or its relevant activities as a concept are seen as continuous development and improvement, with long-term benefits acquired by attentive and sustainable design engineering work.

Focusing on design for environment implementation

The empirical material in this study is mainly concerned with integrating the DFE activities while keeping focus on improved product design and sustainability creation. Interviewees considered the approach to implementing the DFE concept or environmental issues during product development was adequate for their objectives.

From the interviewees, a thorough analysis can be noticed. At first, the company should consider environmental issues in order to fulfil product design requirements, as well as sustainability goals. The company needs to include strategic perspectives or life cycle thinking, as long-term sustainability may drive the design team to reassess their product approach. Design aspects may include the company analysing the material's recycling, reusing, and recovering prospects, and determining the level of unwanted emissions and energy consumption during the product development phases. Second, the company should monitor or define environmental or sustainable targets or criteria at the initial phase of the product design process. These sustainability requirements and targets are weighted equally with other activities and operations in the product development process. Thirdly, the company should focus on identifying and classifying the environmental stakeholders and their requirements. And ultimately, the company should integrate all the activities regarding all the environmental aspects into the design process. DFE activities or the DFE process focus on optimizing the product development process, selecting raw materials, optimizing energy efficiency and providing sustainable solutions for product design and development.

The empirical findings in this study identified activities or themes related to design for environment aspects that are important to the success of the product development and creation of sustainability capability (Table 11).

Table 11. DFE activities and the sustainable actions for the creation of sustainable product development

Key activities/themes	**Actions and their significance for integrating environmental aspects into product development for sustainability capability creation**
Strategic/life cycle perspectives	Include lifecycle perspectives in product development to address environmental issues. Company set a focus for sustainability-driven amendment in product development related to the creation of sustainable product.
Sustainablity target setting	It is important to set the sustainability target in product development to conduct sustainability-driven changes and solutions.
Stakeholder analysis and classification	Environmental stakeholders ought to be identified and classified who have direct or indirect influence in making impact on sustainable product development. Stakeholders may have direct decision-making power during product development.
Analysing and prioritizing stakeholder's requirements	Environmental requirements of different stakeholders need to be analysed so that those requirements are considered during the product development. The design team should make sure that all the requirements are fulfilled, and all the environmental issues are considered. The requirements may need to prioritise according to their importance during different phases of product development
Early phase	To ensure environmental adaption of products and hence create sustainable capability, all activities and environmental issues must be integrated early in the product development process.

5 ANALYSIS AND UTILIZATION OF KEY STAKEHOLDERS AND ACTIVITIES OF 'ENVIRONMENT'

Whereas design for environment supports a general approach to sustainable product development, sustainability capability creation itself is a process that results from the inclusion of different activities or DFE processes during the product development process. Considering how different activities can be combined, it is essential to look at the generic process for creating sustainability capabilities. The main idea of DFE is to identify the main environmental stakeholders and analyse and prioritise their environmental requirements during the initial phase of product design, which then creates the sustainability capabilities as the product development progresses.

The key findings are discussed below in Figure 16, which illustrates the different stakeholders of environment that need to be integrated during the early phase of the product development process. Based on the empirical results of this study, the key stakeholders or critical activities of the environment were divided into four significant tiers to highlight their relative relevance during the product development process in creating sustainable capabilities. This categorization into four tiers reflects emerging perspectives on the relationship between various DFE activities and the process of creating sustainability capability.

Each of the activities within the DFE process should be implemented in product development to create sustainability capabilities. The activities or processes need to be integrated with other activities and carry equal weight. For example, life cycle thinking is the initial process or activity that the company has to consider because they want to produce an environmentally friendly and sustainable product. After they have the lifecycle thinking approach, they know their sustainability targets, what they want their product to be, and how their product may impact people and the environment. These should be the preliminary activities or processes in DFE or the sustainability capability creation process.

The DFE process needs to combine the environmental stakeholders and their requirements during the initial phases of the product development process. It is needed to identify the key environmental stakeholders who are influenced or who can influence the

product development process and who are interested in realizing the sustainability targets. The stakeholders should be classified and prioritized. The environmental requirements produced by the environmental stakeholders should be prioritized and balanced to systematically simplify their key stakeholders and requirements, resulting in better decision-making and focusing on the product development process to fulfil the sustainability targets and ultimately create sustainability capabilities.

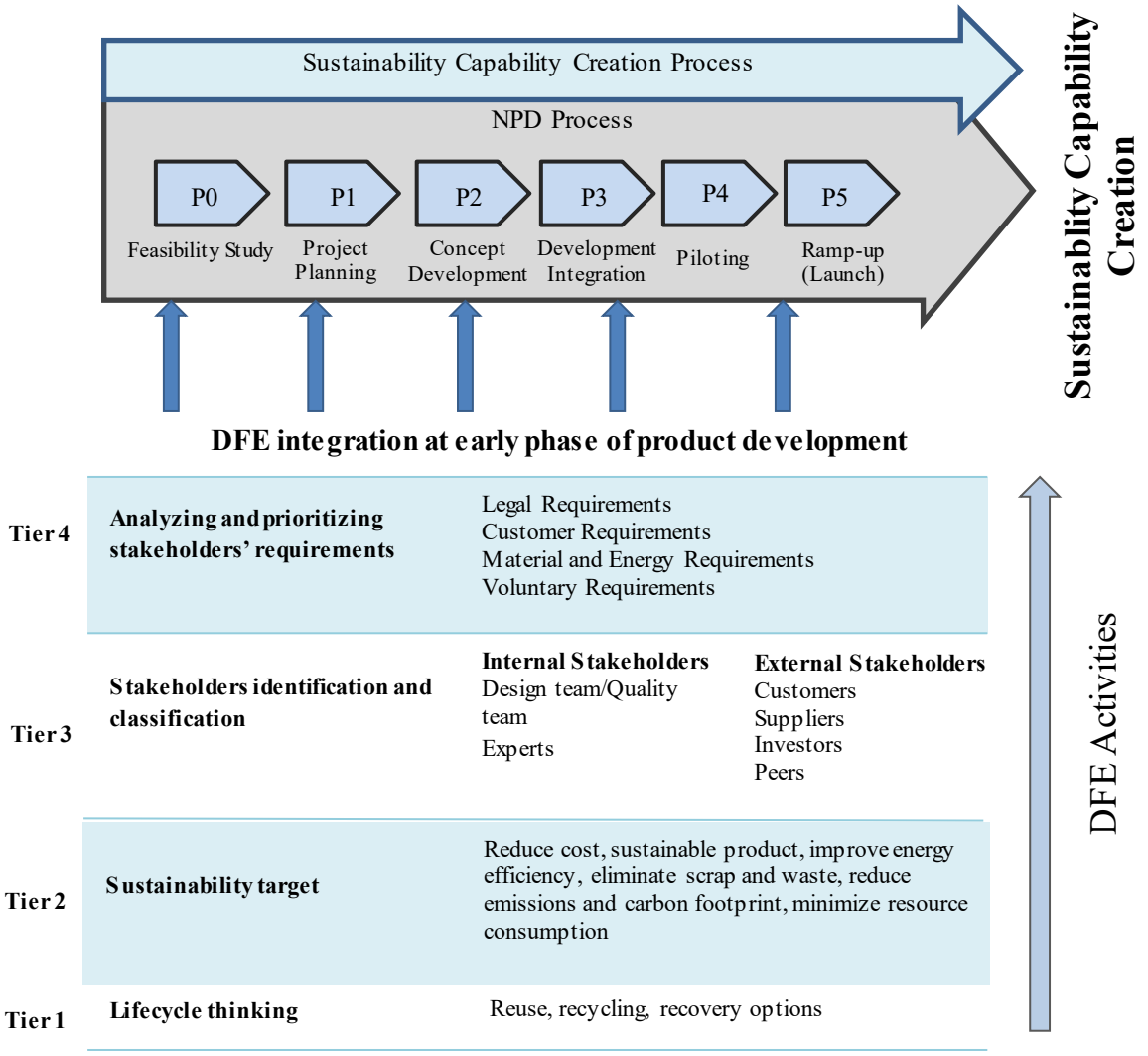

Figure 16. Key activities/stakeholders of environment

5.1 Setting the target for environmental development

For any new product development project to be started, it should be clear what the purpose of development is, what needs the products are fulfilling, what the end product is like, and the main target at the end of the process. Whether environmental improvements and

actions linked to environmental issues in the electronics industry enhance sustainable development is a common question when discussing environmental improvements and activities. This is the subject of integrating DFE practices into the product development process and doing the right things to make a significant difference in the overall environment.

Sustainability capabilities indicate the ways in which the industries constantly reconfigure design for environment concepts to achieve sustainable performances (Singh and El-Kassar 2019) during product development. Moreover, sustainable capabilities imply how industries are involved in developing their products, using the materials and resources in an efficient way to make the products sustainable. Design for environment (DFE) is an emerging concept that improves the environmental performance of electronics industries and thus approaches towards creating sustainability capabilities. DFE is an organized approach to address the key stakeholders and requirements in the early phase of product development and sustainability capability creation. Sustainable capabilities are a result of the performance of the company through the successful implementation of DFE. However, creating sustainable capabilities during the product development process has not been defined in the earlier literature. The efficient production of sustainable products is highly influenced by the early sustainability capability creation activities within the new product development process. The creation of sustainability capability aims to develop an efficient, economical, and sustainable product based on the DFE process.

5.1.1 Life cycle thinking

Effective DFE implementation requires lifecycle thinking and an assessment of the environmental impact of a product and the corresponding environmental targets (Choi et al. 2008). The environmental aspects of the product are initiated and captured by taking the lifecycle perspective into account, the outcome of which is directed towards introducing the targets for sustainability creation, which can be considered as the preliminary activity or steps in the sustainability capability creation process. Lifecycle thinking allows the designer to think about the reuse, recycling, and recovery concepts after the end of the products and intend to set the product design that fulfills those attributes into the products. From lifecycle thinking, the industries need to keep the materials of the products in a sustainable and closed-loop system so that to influence the situations of environmental sustainability (Ulrich and Eppinger 2011). A complete life

cycle (Figure 17) includes stages from the extraction of raw materials to manufacturing processes, distribution, product usage, and end-of-life reusing, recycling, or recovering the product and its components and disposal of the product and its components (Telenko et al. 2008).

The life cycle thinking concept should be considered as the first step during idea generation and new product creation. Therefore, the sustainability capability creation process should start with integrating the life cycle concept with the stakeholders that are associated with the product development process (Jeganova 2004).

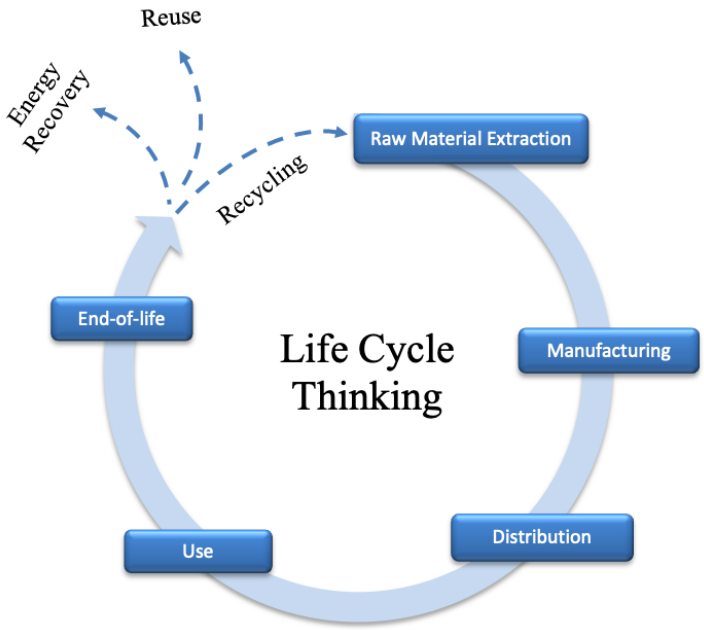

Figure 17. Life cycle thinking should include in product development to address the environmental issues

5.1.2 Sustainablity targets

The sustainability targets should be set during the initial phase of product development. The primary goal of new product development is to fulfill these environmental targets. Environmental targets will need to align with the demands of the stakeholders. The targets should be broad and specific to provide consistent direction for the DFE process (Fitzgerald et al. 2007). Sustainability capabilities are, in a sense, can be considered as these sustainable targets to be fulfilled. Sustainability capabilities are created once these sustainability targets are fulfilled through a new product. The sustainable capability

creation process seeks to minimize the environmental impacts through the efficient use of materials and energy and ensures the production of healthy, sustainable products.

The results of this study highlighted key sustainable targets (Figure 18) for electronics industries that need to be considered at the beginning of the product development process as the initial stages of DFE process in creating sustainability capability.

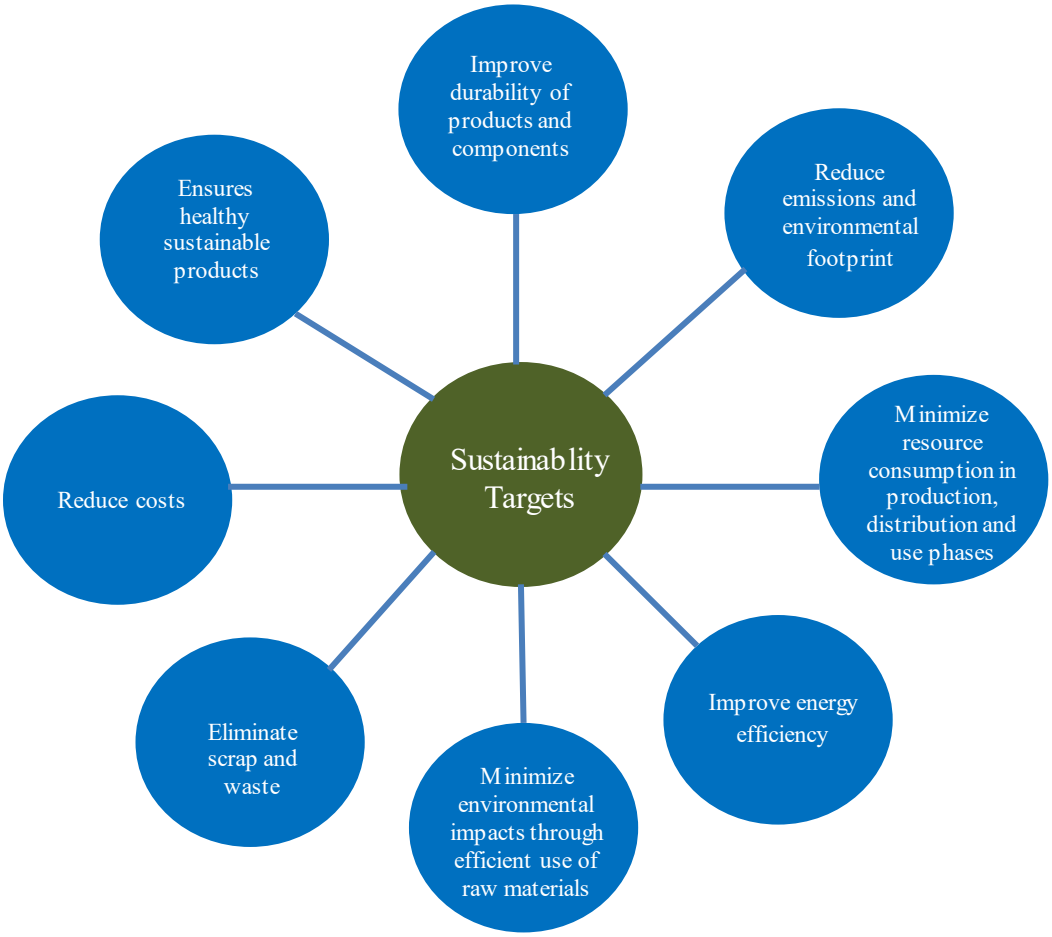

Figure 18. Sustainability targets are set at the beginning of the product development phase to conduct the sustainability-driven changes and solutions

5.2 Identifying and analysing environmental stakeholders

At the beginning of the project, the main task for creating the sustainability capability is to set a clear definition that includes the project goals and the sustainability targets. The definitions lead to the recognition of which types of environmental stakeholders are required (Razali and Anwar 2011). Stakeholders are people or organizations that offer

specific values and preferences to a project (Razali and Anwar 2011) and are involved directly or indirectly in the decision-making process during product development (Vogler et al. 2017). Environmental stakeholders are influenced or have an influence on environmental aspects of product development and are involved in the sustainability creation process. These stakeholders can be internal or external, both having specific roles in the product development process. Internal stakeholders are formal members within the organization, and external stakeholders are informal members outside of the organization but have a great extent of influence on the product development project (Majava et al. 2015). The results of this study suggest key internal stakeholders such as business groups, experts, product design teams, or quality teams, and key external stakeholders such as customers, suppliers, investors, and peers in the industry (Figure 19), that have an impact on the product development process and the creation of sustainability capabilities.

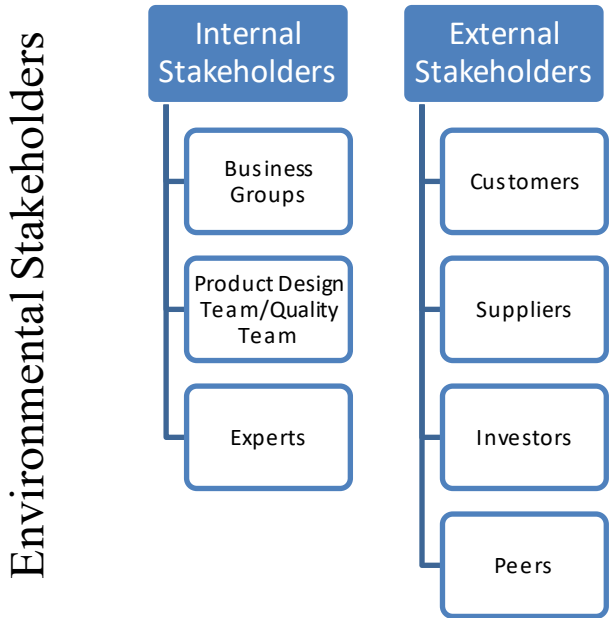

Figure 19. Environmental stakeholders and classification

Each stakeholder has different environmental interests and demands that the company has to meet to a significant degree. In addition, each stakeholder has a different decision-making influence in product development. Thus, it is necessary to prioritize stakeholders based on their influence on decision-making and requirements in the organization (Fitzgerald et al. 2007). This study does not focus on making salience assessments. However, the environmental stakeholders are documented based on their influence, if they have more power, legitimacy, or urgency. Table 12 documents the classifications of environmental stakeholders based on power, legitimacy, and urgency.

Table 12. Environmental stakeholders and their classifications attributes based on power, legitimacy, and urgency

Environmental Stakeholders	Descriptions	Classification Attributes
Internal Stakeholders		
Product Design Team/ Experts/Business Groups	- they have direct decision-making power over the product features, material selections, and so on. - they are liable for fulfilling and complying with all the legislation and regulations during the product development process.	Power, Legitimacy
External Stakeholders		
Customers	- the company should pay precise attention on what customers are requesting. Their requirements and needs are urgent matter that needs to be analysed and notified. - they don't have decision making power over the product development process.	Urgency
Suppliers	- suppliers should look environment and sustainability in the same way the company is looking at. - suppliers provide environmentally friendly products and materials complying with rules and regulations. - They maintain their value by discontinuing supply of a product or materials if they realize that the company is not complying with regulations or if the company is unwilling to accept more environmentally friendly products or materials	Legislative, urgency
Investors	- they have power to influence public reactions for or against the organizations - they might not have direct decision-making power, but they are involved in decision-making process during the product development and they have all the information regarding the sustainability aspects of the products - company needs to regularly update and provide the information regarding the product development process.	Power, urgency
Peers	- the company operates with peers in certain number of aspects, when dealing with supply chain, or making changes to work together - similarly, it is important to track what the peers are producing and if they are considering the environment and sustainability issues as well.	Urgency, legislative

5.3 Analysing the stakeholder's requirements

The environmental stakeholders produce different kinds of environmental requirements, and the companies move towards sustainability creation motivated by these environmental requirements from the stakeholders (Bai and Sarkis 2010). Design for environment activities includes analysing and prioritising these environmental requirements that the company needs to consider during the product development process, and it is a crucial activity of the sustainable capability creation process. The stakeholders' requirements are analysed based on their importance in fulfilling the objectives with three different companies.

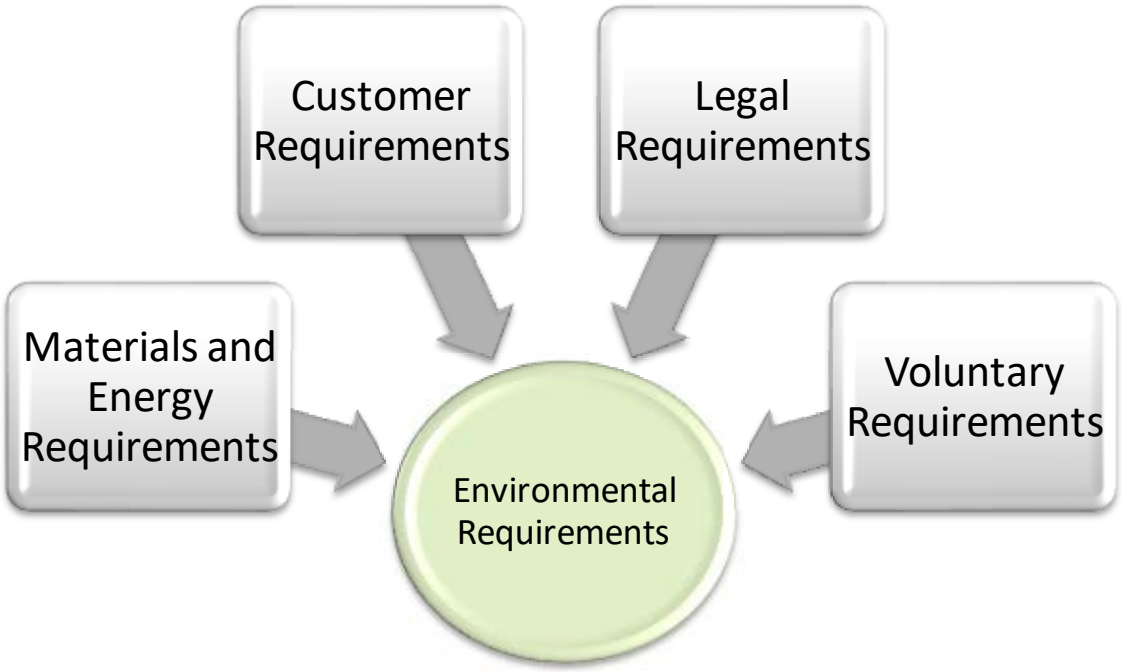

Figure 20. Most important environmental requirements for electronics industry

Figure 20 shows the environmental requirements that are most important for the electronics industry in fulfilling the sustainable objectives and thereby creating the sustainability capabilities. The four important environmental requirements are material and energy requirements, customer requirements, legal requirements, and voluntary requirements. Figure 21 in other hand displays mapping of different environmental requirements produced by different environmental stakeholders.

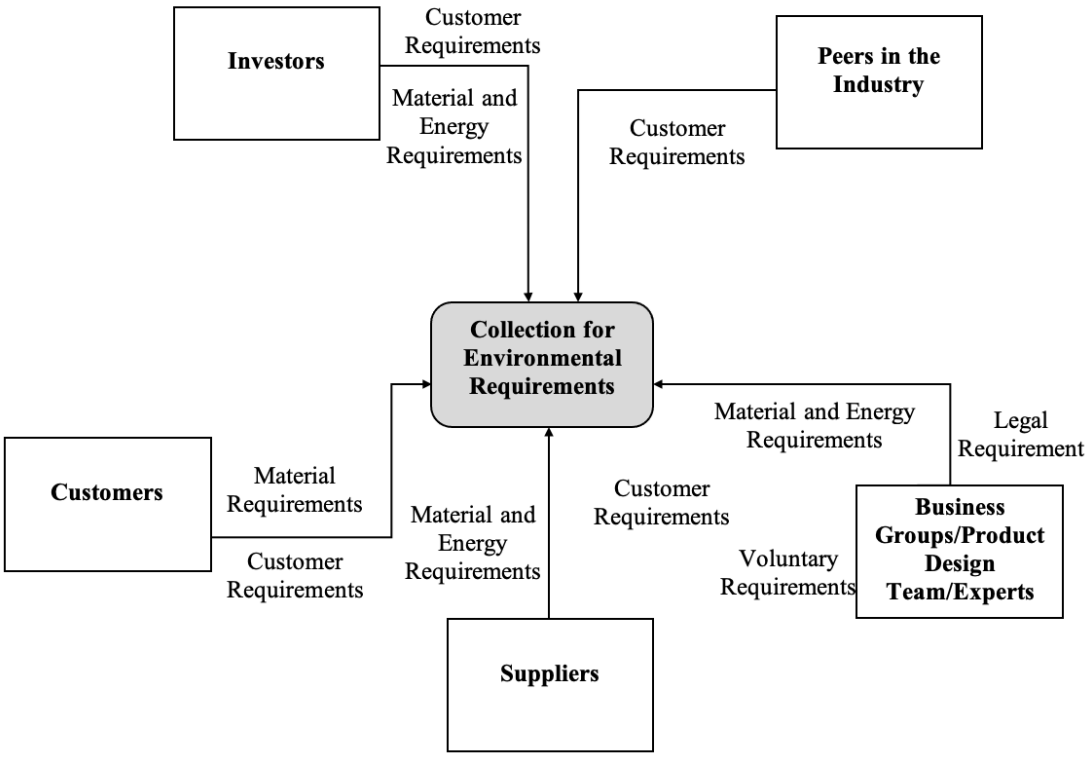

Figure 21. Environmental requirements from different environmental stakeholders

5.4 Balancing the requirements during product development

All the requirements produced by the stakeholders are not, or may not be, of equal importance. Furthermore, the requirements of various stakeholders may conflict with each other. Thus, the requirements must be balanced during the product development process (Bendjenna et al. 2012). Therefore, the requirements have to be prioritized and defined at what stages of the product development process they should be involved. This study does not focus on prioritizing environmental stakeholders based on a specific framework, but the requirements are prioritized based on flexibility and level of importance. Figure 22 shows a simple pyramid for prioritizing environmental requirements based on their level of importance.

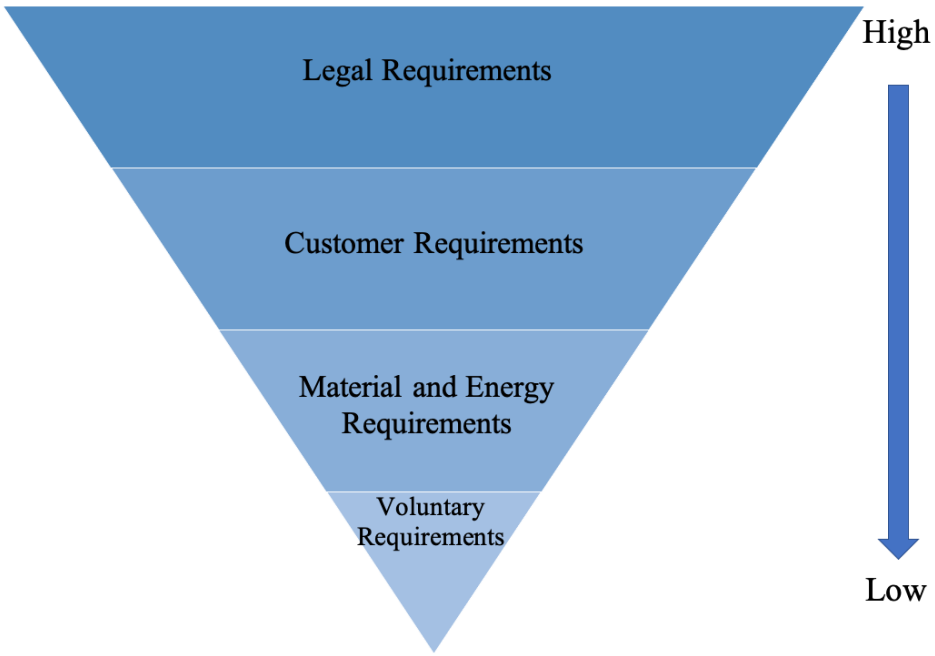

Figure 22. Environmental requirements prioritization based on level of importance

This study indicates that legal requirements are the most critical environmental requirements because they are hard requirements and cannot be changed or altered. There is no negotiation with legal requirements. The company must follow and fulfil all the regulations and rules that come around product development. The legal requirements must be involved during the initial phase of the product development process, and they should be regularly updated throughout the development process. The legislation can be changed at any point during the product's development, and the company should be aware of it. So, legal requirements should be involved from the initial to final phases of product development.

The second most important set of requirements are the customer requirements. The company must meet the needs and demands of the customers. However, they are not hard requirements. They can be negotiated to a certain extent. The customer requirements may include selecting materials, durable products, reusable products and their components, environmentally friendly products, and ultimately product costs. At the beginning of the product development phase, customer requirements should be considered to design the product based on the customer's needs and requirements. Customer requirements may change during the later phase of the product development process, and it may need to make changes at this stage of the development process, depending on the type and extent of demands and requirements of the customer.

Then come the material and energy requirements. Companies want to minimize the use of materials and energy in their products. Moreover, it is important to look at the environmental aspects when selecting materials. Also, the company tries to improve energy efficiency during different phases of the product development process. Therefore, the material and energy requirements should be considered in the early phase of the product development process, and they should be considered throughout the development process. The material requirements run parallel with the legal requirements in the product development phase. Legal requirements may include the selection of material types, and thus, if legal requirements regarding the material and the components change during the development process, they have to be changed.

Finally, the least important requirement, which is still a part of environmental requirements, is voluntary requirements. This requirement comes from the viewpoint that the company wants to change the world and contribute towards sustainable development. They might not be bound by legal or customer requirements, but they want to do something good for the environment and society. For instance, they want to minimize unrecyclable materials and components in the product because they want to contribute. So, they have these kinds of voluntary requirements in place. The voluntary requirements are recognized during the initial phase of the product development process.

Overall, all of these environmental requirements are associated with the creation of sustainability capability. Therefore, the company must consider all environmental requirements during the early phase of the product development phase. Figure 23 describes in detail the involvement of environmental requirements during the product development phases.

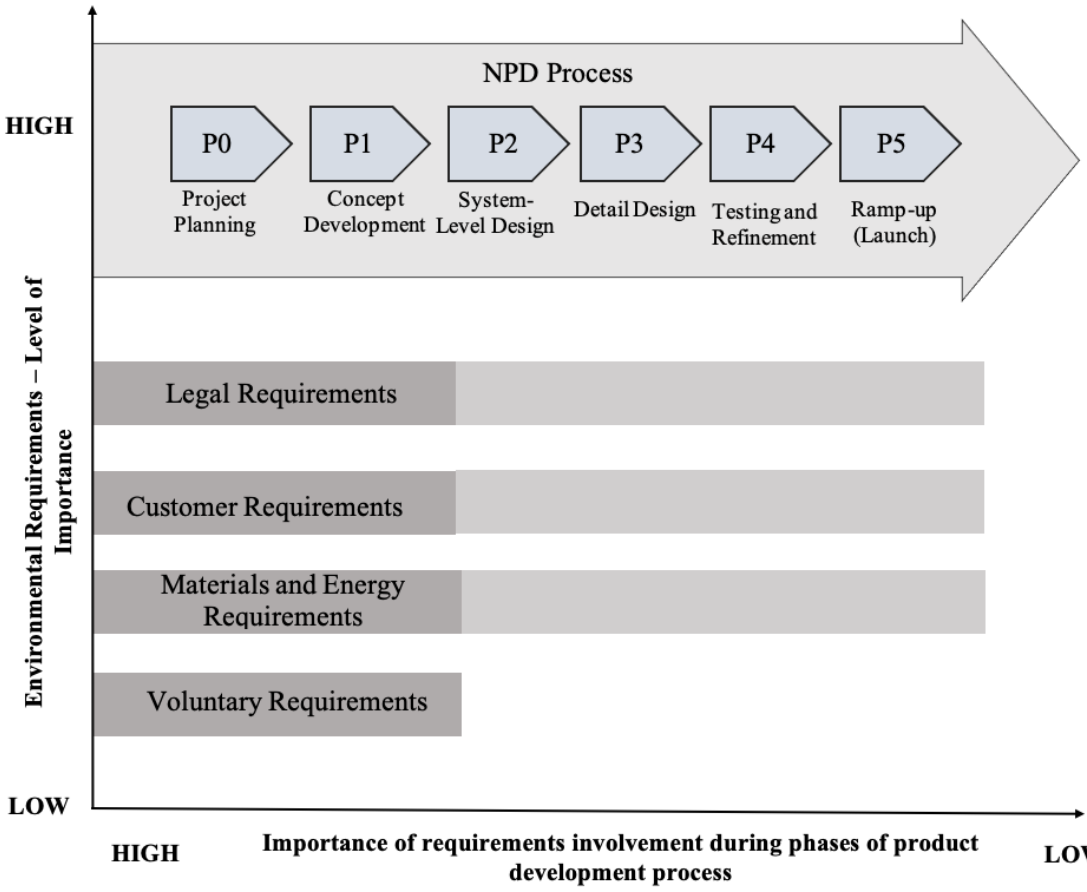

Figure 23. Environmental requirements involvement during stages of product development process. All the requirements are important to be involved and recognized during the initial design phase of product development process. As the product development progresses, the importance of these requirements becomes minimum, but still need to consider and update the requirements until the end of the product development process. Voluntary requirements may not have to be changed at the later phases of product development

5.5 DFE integration into early phase of product design and development process

The product design and development process may vary from company to company and between different products. Thus, the process of integration of environmental aspects may vary too independently within a company. However, the generic approach and the intention can be similar and can be summarized.

The decision-making process should be done in the early stage of the design phase of the product. According to Ramani et al. (2010), decisions made during the early phase have

the potential to affect 70-80% of manufacturing costs while also having an impact on the environment through the use of hazardous materials and substances, which can result in environmental harm during the production, use, and disposal phases of the product's life cycle. Thus, integrating environmental aspects into the early product development phase is crucial to developing sustainable products and achieving environmental objectives.

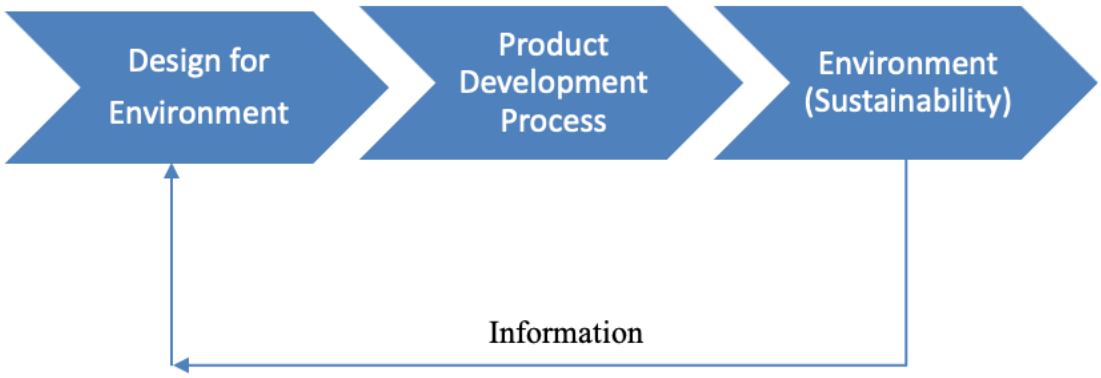

Figure 24. An overview of DFE integration into product development process

The DFE concept can be viewed from different perspectives and can be defined differently depending on the type of industry and its necessities. The perspectives on the environment for different companies are summarized in section 4.3.1. Not all companies regard DFE as a discrete product development concept. However, all of them consider the environmental aspects of product design and the development process, which implies that they follow the idea of DFE to some degree. To fully realize the potential of the DFE concept, it must be further explored and incorporated into the product development process to extract its value and direct the industry toward more sustainable development.

The focus of DFE should be simplified. "E" represents the environment and should be considered during different lifecycle stages such as material use, manufacturing, distribution, product use, and end of life. However, DFE as a concept should be implemented early in the product's design phase to assure that the environmental impacts of the product's lifecycle are recognized before further decisions are made in product development. Therefore, DFE needs to integrate a variety of operations, including environmental impact assessments, data collection and management, design optimization (Choi et al. 2008), sustainability goals, stakeholder analysis, and analysis and prioritizing the stakeholders' requirements.

6 CONCLUSIONS

6.1 Contribution of the research

This study had three major aims: (1) to briefly describe and study the design for environment and capability creation concept, (2) to analyse the generic design for environment stakeholders and their requirements, and (3) to review how the stakeholders and requirements can be combined. In chapter 2, the design for environment and capability creation based on literature analysis and preliminary answers to the first research question were provided. In chapter 3, the methodology used for this study was described. In chapter 4, the practices of the electronics and high-tech industries and the answers to the second research question were addressed. Finally, in Chapter 5, further analysis on stakeholders of environment was performed for practical applications, thereby addressing the third research question.

RQ-1: How can design for environment and capability creation be combined into a unified sustainability concept?

Design for the environment is an approach to the product development process that aims to improve the environmental capabilities across the product's entire lifecycle. The central aim of design for environment is to achieve sustainability targets, and design for environment aids product development in achieving sustainability capabilities. Design for environment and sustainability capability creation are counterpart activities that support one another in a cycle. They both impose and make use of identifying and assessing critical environmental stakeholders during the product development process for long-term sustainability. During the initial product development phase, the sustainability capability creation process focuses on the design for environment product aspects, attitudes, targets, and related actions and requirements. The sustainability capability creation process focuses on developing strategic sustainable products.

DFE implementation in new product development influences environmental execution in facilitating sustainable product design. With the environment as a significant X, early integration of design for environment in product design is critical to comprehensive sustainable capability creation, with sustainability being the primary capability developed at the end of the product development process. Thus, design for environment to product

development process improves product competitiveness by ensuring sustainability creation.

The design for environment and capability creation are interlinked to each other and should not be considered as two different aspects or concepts. While design for the environment focuses on environmental or sustainable aspects of the product, the capability creation process focuses on improving product design and ensuring efficient product design and implementation through pre-planning and a set of supportive actions and activities. The capability creation process may fill the voids in the design phase, with fundamental DFE activities and processes serving as cornerstones. In general, the execution of the capability creation process is aided by a generic design for environment process, where sustainable product design or sustainability as a combined concept can be used to define design for environment and capability creation (process) when considered together in the product development process.

RQ-2: What are the generic DFE stakeholders and requirements for product development?

Because of the increasing complexity of environmental issues, the design team must undertake research, actively engage stakeholders, and acquire knowledge and information from them. Stakeholders provide information to help with the product life cycle process, which is critical for designing environmentally friendly products. There are two types of DFE stakeholders: the first is internal stakeholders, who are from within the organization, actively participate in the product design and development process, and can influence decision-making during product development. From an indirect engagement viewpoint, the second type is external stakeholders outside the organization that do not have decision-making authority but significantly impact the product design and development process.

This study has presented a simple model of network of environmental stakeholders (see fig. 14 and table 8) around product development in the electronics industry. The key internal stakeholders are business groups, the design team, the quality team, and experts who directly influence the product development process and who have the power to control from the standpoint of using design for environment activities, processes, and requirements.

The primary external environmental stakeholders are customers, who are the end-users of the product; suppliers/supply chain, where the sourcing of materials comes from; investors or the investment community that invest in the company in different ways; and the peers in the industry who cooperate in a certain number of aspects to address certain kinds of issues and to have electronics product manufacturers towards their supply chain and to make changes together.

The key environmental stakeholders carry essential environmental requirements that the company must consider while making distinct changes and improvements in the new product development process. The generic design for environment requirements (see table 7) for product development includes legal requirements, customer requirements, materials and energy requirements, and voluntary requirements.

RQ-3: How can stakeholders and requirements be combined in the generic level to fulfil environmental requirements?

The extended model has been suggested in chapter 5 (fig 16) to describe how to combine stakeholders and requirements to fulfil environmental requirements.

Design for the environment provides a comprehensive framework for sustainable product design. The creation of sustainability capabilities is a process that comes from integrating various DFE activities during product development. Therefore, assessing the generic process for developing sustainability capabilities is crucial when analysing how different activities could be integrated. The fundamental idea behind DFE is to identify the significant environmental stakeholders and analyse and prioritize their environmental requirements during the initial phase of product design, which subsequently results in the creation of sustainability capabilities as product development proceeds.

The key stakeholders or activities of the environment were categorized into four significant tiers based on the empirical results of this study to emphasize their significance during the product development process in fulfilling sustainable requirements. The tiers represent emerging insights on the connection between various DFE activities and the process of developing sustainability capability.

The first tier represents the lifecycle thinking approach the organization must consider producing an environmentally friendly and sustainable product. The second tier is setting their sustainability targets. Sustainability targets should be identified early in the product development process. These environmental targets are the main objective of new product development. Environmental targets must be in line with stakeholder expectations. The targets should be extensive and detailed in order to give consistent guidance for the DFE process. These should be the preliminary actions in creating sustainable capabilities. The critical environmental stakeholders who impact or can impact the product development process should be identified and concerned with achieving the sustainability targets. The third tier is identifying and classifying the stakeholders. The fourth tier is the environmental requirements created by environmental stakeholders. They should be analysed, prioritized, and balanced to optimize the key stakeholders and requirements sequentially, resulting in improved decision-making and focus on the product development process to meet sustainability targets.

6.2 Evaluation of the research

Quality of the research is evaluated by its validity and reliability. Validity defined as "*the issue of whether an indicator that is devised to gauge a concept really measures that concept"* (Bryman 2012) measures the quality of a case study research, which can be constructed by using multiple sources of evidence and cross-verifying them (Kristinsdottir 2016). Validity can be construct validity, internal validity, and external validity (Yin 2014). Reliability assesses the consistency and repeatability of the research process (Yin 2014).

Construct validity is the degree to which proper operational assessments for the concepts being studied can be identified. Construct validity may be strengthened by employing a variety of research materials, developing a chain of evidence, having key informants evaluate the draft report, and using similar metrics as in similar studies. (Yin 2014)

A literature review and an empirical survey were employed as research methods in this study. The theoretical research was compiled from research articles and a few textbooks. For completing a literature study, research papers and textbooks were the most feasible and reliable sources of information. The most relevant aspects of the reading materials

were highlighted and categorized in constructing the correct structure of the theory in order to penetrate the concepts of design for the environment briefly.

The questions were designed based on the theoretical study and addressed the key aspects of design for environment activities and viewpoints. The interviews were conducted with experts and persons at managerial levels who could answer the questions without difficulties. The responses were generic and could be combined. The basic concept and aims of the study were explained to the interviewers at the outset. As a result, the outcomes are broad and generic. However, the number of interviews, which was limited to three, could have been increased to improve the diversity of the answers.

The research methodologies are described in detail in Chapter 3. In the empirical study, qualitative methodologies were applied, and the findings of the interviews were summarized and analysed. The conclusions have been developed based on the findings and analysis.

Because the chosen measures are practical for the study, the overall construct validity of the study may be presented as an average. Although the number of interviews was low, it aided in conducting a more in-depth analysis.

Internal validity is the extent to which the research methods used, the results of the study interpreted accurately and whether the research findings are within the quality of the interviews and are subjected towards the theoretical framework (Yin 2014; Saunders & Lewis 2012). To reduce the threat and construct internal validity, a valid interview guide and question topics were prepared that mainly consisted of questions regarding environmental perspectives and DFE/DFX approaches of the studied companies. Only selected companies were chosen for the interviews, who then decided, whether they were interested in helping with the research. The results and findings from the interviews were cross verified with the available literature and other secondary data such as company's webpage and the background information about the company. The internal validity of this study can be stated as *high*.

External validity is based on the research design. To reduce the threat to external validity, the participants were carefully selected. The study has been conducted on companies based on consumer electronics and high-tech industries who have integrated sustainability

into their business and whose products/services are based on sustainable approach and are based on Finland. Thus, the analysis made in this study can be considered as appropriate for the specific areas of industries, i.e., consumer electronics and/or high-tech industries. The approach and strategy may differ for other industries. The output of this study can be regarded as a generic analysis through the combination of literature study and the empirical results and can be pertinent to much wider range of contexts. The external validity of this study can be thus regarded as *low*.

Reliability defined as "*the degree to which a measure of a concept is stable"* (Bryman 2012) refers to consistency in findings through multiple data collection methods and analysis procedures (Saunders & Lewis 2012). There might rise the threat to the reliability of the research findings and conclusions because of certain biases and errors (Flikweert, 2015). The participants were explained about the research topics and research goals in advance to reduce the subject bias. The participants were allowed to choose the time and/or ways they feel appropriate for the interview. Semi-structured interviews were used based on a list of relevant topics and predetermined questions. The interviews were recorded and transcribed for analysis to reduce the observer bias.

It is very important to maintain the confidentiality and trust between the researcher and the research subjects for the quality and the authenticity of the research. The participants who participated in the interviews were pre-informed clearly about the research process and how their names and information would be used in the thesis to build the trust between the researcher and the participants. Permission to record the session was explicitly asked before conducting the interviews with the participants. No sensitive and/or detailed information about the company and/or their products were asked during the interviews.

6.3 Suggestions for further research

The DFE concepts have been discussed widely in the theoretical bases. However, its practical utilization and realization in the companies have not been explored sufficiently. Moreover, there has been very limited research done in the electronics industries regarding the design for environment and its surroundings aspects. Further research should focus on assessing the performance of actual scenarios and making comparisons with experimental scenarios that use more organized DFE methods and approaches.

This study lays the foundation for future research into DFE-oriented methods for the design and development of electronic products and the connection between the design process and the product's life cycle pertaining to the implications for human and environmental health. Further study might involve analyses of specific attributes or themes connected to the design for environment approach to add to the issue and provide a holistic view of the DFE procedures used in the electronics industry.

Researchers must be allowed to compare possible product design concepts with current product designs and should be provided with the opportunity to choose design constraints that improve the product's long-term sustainability. Further research on the topic would include the practical development of such DFE tools. The DFE tools must therefore be able to assess different design options and draw significant results.

Further research in this area could be focused on the environmental information of the product. In the future, environmental regulations and legislation will emphasize providing environmental information of products and their aspects. As a result, it is essential to conduct research on what type of relevant information related to environmental aspects is necessary for various stakeholders in the electronics industry.

The methods utilized for research in this field should be broadened in order to improve research on how to include environmental issues in the product design and development process. Multiple sources might be employed to gather data and information to broaden the issues and acquire a more thorough knowledge. More case studies and qualitative research should be considered in the future study.

REFERENCES

Bai, C., & Sarkis, J., 2010. Integrating sustainability into supplier selection with grey system and rough set methodologies. International Journal of Production Economics, 124(1), pp. 252-264.

Baxter, P. & Jack., S., 2008. Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. The qualitative report, 13(4), p. 544-556.

Belt, P., Harkonen, J., Mottonen, M., Kess, P., & Haapasalo, H., 2008. Improving the efficiency of verification and validation. International Journal of Services and Standards, 4(2), pp. 150-166.

Bendjenna, H., Charre, P-J., & Zarour, N.E., 2012. Using multi-criteria analysis to prioritize stakeholders. Journal of Systems and Information Technology, 14(3), pp. 264-280.

Boks, C., & Stevels, A., 2007. Essential Perspectives for Design for Environment, Experiences from the Electronics Industry. International Journal of Production Research, 45(18-19), p. 4021-4039.

Bryman, A. 2012. Social Research Methods. Oxford U.K., Oxford University Press.

Chiu, M.C., & Kremer, G.E.O. Investigation of the Applicability of Design for X Tools during Design Concept Evolution: A Literature Review. International Journal of Product Development, 13, pp. 132-167.

Choi, J.K., Nies, L.F., & Ramani, K., 2008. A framework for the integration of environmental and business aspects toward sustainable product development. Journal of Engineering Design, 19(5), pp. 431-446.

Cooper, R.G., 2001.Winning at New Products: Accelerating the Process from Idea to Launch. Third Edition. Cambridge, Massachusetts: Perseus Publications.

DeMendonca, M., & Baxter, T.E., 2001. Design for the environment (DFE) – An approach to achieve the ISO 14000 international standardization. Environmental Management and Health, 12(1), pp. 51-56.

Fiksel, J., 1993. Design for environment: an integrated systems approach. Proceedings of the 1993 IEEE International Symposium on Electronics and the Environment, pp. 126-131.

Fitzgerald, D.P., Herrmann, J.W., Sandborn, P.A., Schmidt, L.C., & Gogoll, T.H., 2007. Design for Environment (DfE): Strategies, Practices, Guidelines, Methods, and Tools. Environmentally Conscious Mechanical Design, M. Kutz, ed., Wiley, Hoboken, NJ.

Fllikweert, B., 2015. *How are sustainable business opportunities formed? A qualitative analysis of sustainable opportunity identification in Dutch SME's.* (Unpublished master's thesis). Tilburg University, Tilburg.

Gatenby, D.A., & Foo, G., 1990. Design for X (DfX): Key to Competitive, Profitable Products. AT&T Technical Journal, 69(3), pp. 2-13.

Glazebrook, B., Coulon, R., Abrassat, C., 2000. Towards a Product Lifecycle design tool. Proceedings of the 2000 IEEE International Symposium on Electronics and the Environment, IEEE, pp. 81-85.

Gungor, A., Gupta, S.M., 1999. Issues in Environmentally Conscious Manufacturing and Product Recovery: A Survey. Computers & Industrial Engineering, 36(4), pp. 811-853.

Halttula, H., Haapasalo, H., Aapaoja, A., & Manninen, S. (2017). Early Involvement and Integration in Construction Projects: The Benefits of DfX in Elimination of Wastes. International Journal of Management, Knowledge and Learning, 6(2), pp. 215-237.

Harkonen, J., Belt, P., Mottonen, M., Kess, P., & Haapasalo, H., 2009. Maturity of verification and validation in ICT companies. International Journal of Innovation and Learning, 6(1), pp. 33-50.

Hauschild, M., Jeswiet, J., Alting, L., 2004. Design for Environment – Do We Get The Focus Right? CIRP Annals, 53(1), pp. 1-4.

Helo, P., 2004. Managing agility and productivity in the electronics industry. Industrial Management & Data Systems, 104(7), pp. 567-577.

Holt, R., & Barnes, C., 2010. Towards an integrated approach to "Design for X": an agenda for decision-based DFX research. Research Engineering Design, 21, pp. 123-136.

Huang, G.Q., 1996. Implementing Design for X Tools. In: Huang, G.Q. (eds) Design for X. Springer, Dordrecht.

Jeganova, J., 2004. *Product Life Cy le Design: Integrating Environmental Aspects into Product Design and Dev3lopment Process at Alfa Laval.* Master's thesis. Lund University, Sweden.

Junning, S., Bin, H., Stephen, E.O., & Hong-Chao, Z., 2003. DESIGN FOR ENVIRONMENT: METHODOLOGIES, TOOLS, AND IMPLEMENTATION. Journal of Integrated Design & Process Science, 7(1), pp. 59-75

Kinnunen, T., Aapaoja, A., & Haapasalo, H., 2014. Analyzing internal stakeholders' salience in product development. Technology and Investment, 5(2), pp. 106-115.

Kristinsdottir, I.M., 2016. *The natural entrepreneur: The role of natural resources in sustainable opportunity creation.* (Unpublished master's thesis). University of Oslo, Oslo.

Kuo, T.C., Huang, S., & Zhang, H.C., 2001. Design for manufacture and design for 'X': Concepts, applications, and perspectives. Computers & Industrial Engineering, 41(3). DOI: 10.1016/S0360-8352(01)00045-6

Kurk, F., & Eagan, P. The Value of Adding Design-For-The-Environment to Pollution Prevention Assistance Options. Journal of Cleaner Production, 16(6), pp. 722-726.

Lagerstedt, J., 2003. *Functional and Environmental Factors in the Early Phases of Product Development – Eco Functional Matrix*. PhD Thesis, KTH, Stockholm.

Lagerstedt, J., Luttropp, C., & Lindfors, L-G., 2003. Functional priorities in LCA and design for environment. The International Journal of Life Cycle Assessment, 8, p. 160-166.

Lau, A.W., Yam, R.C.M., & Tang, E.P.Y., 2007. Supply chain product co-development, product modularity and product performance: Empirical evidence from Hong Kong manufacturers. Industrial Management & Data Systems, 107(7)

Lehto, J., Harkonen, J., Haapasalo, H., Belt, P., Mottonen, M., & Kuvaja, P., 2011. Benefits of DfX in Requirements Engineering. Technology and Investment, 2(1), p. 27-37.

Lenox, M., King, A., & Ehrenfeld, J., 2000. As Assessment of Design-for-Environment Practices in Leading US Electronics Firms. Informs Journal on Applied Analytics, 30(3), pp. 83-94.

Luttropp, C. & Lagerstedt, J., 1999. Customer benefits in the context of life cycle design. Proceedings First International Symposium on Environmentally Conscious Design and Inverse Manufacturing, pp. 482-487.

Majava, J., Harkonen, J., Haapasalo, H., 2015. The relations between stakeholders and product development drivers: practitioners' perspectives. International Journal of Innovation and Learning, 17(1), pp. 59-78.

Mathur, N., 2007. *Implementation of design for environment principles in product development using a case study on the design of a passenger car,* Durham theses, Durham University. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/2457/

Miles, M.B., & Huberman, A.M., 1994. Qualitative Data Analysis, an extended sourcebook. Sage Publications, London, UK.

Mustonen, T., 2009. *Design for X in high technology companies – theory and practice behind downstream-conscious product development.* (Unpublished master's thesis). University of Oulu, Oulu, Finland.

Möttönen, M., Härkönen, J., Belt, P., Haapasalo, H., & Similä, J., 2009. Managerial view on design for manufacturing. Industrial Management & Data Systems, 109(6), pp. 859-872.

Pahl, G., Beitz, W., Feldhusen, J., & Grote, K.H., 2007. Engineering Design – A Systematic Approach. Third Edition. Springer-Verlag London Limited, London, UK.

Ramani, K., Ramanujan, D., Bernstein, W.Z., Zhao, F., Sutherland, J., Handwerker, C., Choi, J-k., Kim, H., & Thurston, D., 2010. Integrated Sustainable Life Cycle Design: A Review. Journal of Mechanical Design, 132(9), pp.1-15.

Razali, R., & Anwar, F., 2011. Selecting the right stakeholders for requirements elicitation: A systematic approach. Journal of Theoretical and Applied Information Technology, 33(2).

Rose, C.M., 2000. *Design for Environment: A Method for Formulating Product End-of-Life Strategies.* Ph.D. thesis, Stanford University, Palo Alto, CA.

Rounds, K.S., & Cooper, J.S., 2002. Development of product design requirements using taxonomies of environmental issues. Research in Engineering Design, 13(2), pp. 94-108.

Telenko, C., Seepersad, C.C., & Webber, M.E., 2009. A method for developing design for environment guidelines for future product design. *In: ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference,* number DETC2009-87389, August-September, San Diego, CA. New York, NY: ASME International, 291-302.

Telenko, C., Seepersad, C.C., & Webber, M.E., 2008. A Compilation of Design for Environment Principles and Guidelines. Proceedings of the ASME 2008 International Design Engineering Technical Conferences and Computers and Information in Engineering Conferences. Volume 5: 13th Design for Manufacturability and the Lifecycle Conference; 5th Symposium on International Design and Design Education; 10th International Conference on Advanced Vehicle and Tire Technologies. Brook, August 3-6, Brookklyn, New York, USA, pp. 289-301.

Tolonen, A., Haapasalo, H., Harkonen, J., & Verrollot, J., 2017. Supply chain capability creation – The creation of the supply chain readiness for a new product during product development process. International Journal of Production Economics, 194, p. 237-245. https://doi.org/10.1016/j.ijpe.2017.09.007

Saunders, M., & Lewis, P., 2012. Doing Research in Business & Management: An Essential Guide to Planning Your Project. Harlow: Financial Times Prentice Hall.

Schell, C., 1992. The value of the case study as a research strategy. Manchester business school, 2, p.1-15.

Singh, S.K., & El-Kassar, A-N., 2019. Role of big data analytics in developing sustainable capabilities. Journal of Cleaner Production, 213, pp. 1264-1273

Suresh, P., Ramabalan, S., & Natarajan, U., 2016. Integration of DFE and DFMA for the sustainable development of an automotive component. International Journal of Sustainable Engineering, 9(2), pp.107-118.

Ufford, D.A., & Ward, W.J., 1999. Next Generation Design for the Environment Paradigms. Proceeding of the 1999 IEEE International Symposium on Electronics and the Environment, IEEE, pp. 268-273.

Ulrich, K.T., & Eppinger, S.D., 2008. Product design and development. Boston: McGraw-Hill Higher Education.

Ulrich, K.T., & Eppinger, S.D., 2011. Design for Environment. In: Ulrich, K.T., Eppinger, S.D. (Eds.), Product Design and Development. Boston: McGraw-Hill Higher Education.

Vogler, D., Macey, S., & Sigouin, A., 2017. Stakeholder Analysis in Environmental and Conservation Planning. Lessons in Conservation, 7, pp. 5-16

Yang, C.C., Chen, S.H., & Shiau, J.Y., 2007. A DFX and concurrent engineering model for the establishment of a new department in a university. International Journal of Production Economics, 107(1), pp. 179-189.

Yin, R.K., 2014. Case study research: Design and methods. 5th edition. Sage Publications Inc.

Zainal, Z., 2007. Case study as a research method. Jurnal Kemanusiaan, 5(1).

Zeidler, C., Kittl, C., & Petrovic, O., 2008. An integrated product development process for mobile software. International Journal of Mobile Communications, 6(3).

1. How important do you see sustainability in your company?
2. Do you use DFX (Design for Excellence) concept in your company? How?
3. What is environment in your point of view? (nature, material flow, businesses, downstream supply chain in the company, environmental standards and permissions, directives, and so on). How should it be noted?
4. What type of requirements are the most important one in sense of environment? / What are those environmental requirements?
5. How do you manage those requirements in your product development?
6. How are those requirements categorized and prioritised?
7. Who are the stakeholders who presents/carry on those requirements? Who are the environmental stakeholders (internal, external)? (legislative, consumer type, or something else?)
8. How do you classify those environmental stakeholders?
9. Do those requirements change during the product development process?
10. Do you use DFE (Design for Environment) concept in your company? How?
11. How do you acknowledge the design for environment in practice?
    - Product design
    - Material selection
    - Requirements management
    - Production
    - Packaging
    - Service/maintenance
    - Disposal
    - supplier
    - Others?
12. How important do you think the use of DFE concept is at present and in the future?
13. What are the strengths and challenges of the DFE approaches? How to respond on those challenges?
14. Is there anything else you would like to mention about this topic?