LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
Faculty of Technology Management
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INTEGRATING ENVIRONMENTAL ASPECTS INTO PRODUCT DEVELOPMENT PROCESS

Master of Science Thesis

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ABSTRACT

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Various regulations and customer requirements have made it necessary for Vacon Oyj to pay more attention to the environmental aspects in its processes. The main purpose of this master's thesis project is to define how environmental aspects could be integrated into Vacon's product development process. The aim is to find out the most important environmental aspects for the company to address, to examine how these could be taken into account during the development process and to map the critical factors that need consideration in order to ensure the successful integration of environmental aspects into the design process.

Based on the customer requirements and evolving regulations the most important aspects for Vacon include minimizing the amount of harmful substances, improving the recyclability and energy efficiency of the product and moreover providing meaningful information related to these aspects. To tackle these issues, a new DfE process was developed, tasks in each phase were described and responsibilities were indicated. To ensure the success of the DfE process, management commitment, support of other processes and significant improvements in ways the information is managed are required. The developers should be provided with training and support. Environmental expertise and knowledge in-house should be developed and establishing meaningful environmental indicators is suggested.

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Jatkuvasti kehittyvät säädökset ja asiakkaiden kasvavat vaatimukset ovat pakottaneet Vacon Oyj:n ottamaan ympäristöasiat paremmin huomioon prosesseissaan. Tämän diplomityön päätavoite on selvittää kuinka ympäristöasiat tulisi ottaa huomioon jo tuotekehitysprosessin aikana. Tarkoituksena on selvittää yrityksen kannalta tärkeimmät ympäristöasiat, kuinka nämä voitaisiin huomioida jo suunnitteluprosessin aikana sekä tunnistaa kriittiset tekijät, jotka vaikuttavat ympäristömyötäisen tuotekehitysprosessin onnistumiseen.

Kartoitettujen asiakasvaatimusten ja tärkeimpien säädösten perusteella Vaconin kannalta tärkeimpiin ympäristönäkökohtiin kuuluvat haitallisten aineiden ja materiaalien käytön minimointi, tuotteen kierrätettävyyden ja energiatehokkuuden parantaminen ja erityisesti näihin asioihin liittyvän tiedon hallinta ja kattava tarjonta. Tässä työssä kehitettiin nämä asiat huomioon ottava yrityksen tarpeisiin sopiva ympäristömyötäinen tuotekehitysprosessi (DfE). Prosessin vaiheet, tarvittavat tehtävät ja vastuut eri vaiheissa on kuvailtu. Tulevan DfE-prosessin menestyksen kannalta johdon sitoutuminen, yrityksen muiden prosessien tuki, sekä tiedonhallintajärjestelmien ja -menetelmien kehittäminen on välttämätöntä. Suunnittelijoille tulee tarjota koulutusta ja tukea. Yrityksen sisäistä tietotaitoa ympäristöasioiden suhteen on kehitettävä, sekä merkityksellisten ympäristömittarien luominen ja seuranta on suositeltavaa.

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I also want to thank my family for all the support they have provided me throughout my studies. Especially I want to thank my dad for being such an inspiring role model and truly something to look up to. Special thanks to my friends for reminding me of what life is all about and not letting the distance separate us.

I would like to dedicate this master's thesis to the memory of Krishna Khetia, whose joy of living and sparkly appearance as well as her enthusiasm for environmental protection was truly inspiring.

Vaasa, 7th of July, 2011

Jutta Tuominen

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LIST OF ABBREVIATIONS

DfE	Design for Environment
DfX	Design for any desired attribute
ECD	Environmentally conscious design
ECMA	European Computer Manufacturers Association
EEA	Electrical and electronic appliances
E-O-L	End of life
EPD	Environmental product declaration
ERP	Energy related products
EU	European Union
EuP	Energy using products
IEC	International Electrotechnical Comission
IPP	Integrated product policy
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCT	Life Cycle Thinking
MET	Material, energy and toxicity
NPI	New Product Introduction
OEM	Original equipment manufacturers
PCM	Product change management
PDCA	Plan, Do, Check and Act
PDM	Product data management
RoHS	Restriction of Hazardous Substances Directive
REACH	Restriction, evaluation, authorization of hazardous chemicals
R&D	Research and development
WEEE	Waste of Electrical and Electronic Equipment
3S	Solution support and service

1 INTRODUCTION

During the recent years people's awareness concerning environmental issues has risen drastically and it is no longer only the environmentally conscious minority who is concerned about the state of the world we are living in. Rising public concern, tightening regulations, constantly higher customers' and other stakeholders' requirements have made it necessary for the companies to take environmental aspects into consideration more systematically. Companies can no longer ignore environment in their processes and practices.

Even though the environmental problems today are more daunting than ever Joseph Fiksel (2010), one of the famous authors in the field of design for environment (DfE) stays optimistic and believes that environmental sustainability is compatible with economic growth. According to him people are creative enough to overcome these problems. We just have to start acting now.

Focus of the companies' environmental work has shifted from reactive end-of-pipe emission control into more proactive prevention of problems. Different sort of DfE initiatives have been launched by firms seeking to minimize the environmental impact of their products throughout their entire life cycle. Product development has been noted to have the greatest chance to influence the environmental characteristics of the product, and designers are now the ones responsible for developing products with low environmental impact.

The Finnish-based company Vacon is one of these companies seeking to incorporate environmental awareness into their product development process. In the end of the year 2010 a "DfE guide for product development" -project was launched as a first step towards an increased environmental performance of the company and its products.

1.1 Background of the research

The target company of this master's thesis, Vacon Oyj is focused solely on providing AC drives and related services. With AC drive Vacon’s customers can gain substantial energy savings. As a producer of AC drives Vacon is to some extent already contributing to sustainable development. Even though the product itself is environmentally friendly and provides positive solutions to the customers, there are several other environmental aspects to be taken into account. Mainly due to a growing number of customer requirements and constantly evolving environmental regulations the company has faced the need to include environmental consideration into their product development process more systematically.

Vacon collaborates closely with its customers and listens to their needs. These customers’ needs create the foundation for all Vacon processes. Recently the customers have started to require further information regarding to the environmental aspects of the product. Improving the capability to answer to these requirements is one of the key objectives of this project. Also several environmental and industry-specific regulations and directives have an impact on Vacon’s processes. Complying with the relevant regulative constraints is necessary for the company. However, keeping up with the continuously evolving regulations is not always easy.

Need to ensure compliance with the regulations, improve the ability to answer customer requirements and make sure that environmental aspects are included in the product development process initiated the project. This master’s thesis is conducted as a part of the project aiming to map the actions needed for successful integration of environmental consideration into the product development in the company.

1.2 Research objectives

The main objective of this master's thesis is to create a framework for a product development process which integrates environmental consideration systematically into the general product development process of the company. In other words, the aim is to find out how the environmental aspects should be integrated into product development process in the case company. This provides the main research question:

How to integrate the environmental aspects into product development process in the case organization?

In order to answer the main research question it is necessary to provide answers to the following sub research questions.

What are the most important environmental aspects from the point of view of Vacon?

Customers have been increasingly curious about the environmental aspects of the products as well as the environmental performance of the entire company. These customer requirements have been the initial trigger to start the project. Therefore a survey addressing customers' requirements concerning the environmental aspects was conducted. The customers' needs were studied and analyzed to discover the most important and urgent environmental issues to address from the case company's point of view.

How can these environmental aspects be addressed in the product development process?

To find the most suitable ways to integrate environmental considerations into the development process in the case company, environmentally conscious product development process literature and standards are studied alongside with careful examination of the case company's general model of product development process. Also the ways other companies have integrated environmental concerns to their product development have been studied.

What are the critical factors to consider in order to ensure successful integration of environmental aspects into the design process?

In order to ensure that DfE practices are integrated into the development process successfully it is necessary to identify and comprehend the essential supporting elements of DfE. To gain the understanding needed the literature review is conducted. Also IEC's standard for environmentally conscious design was found suitable and was studied more thoroughly.

1.3 Scope

This thesis focuses on the product development process of the company. Due to the interconnected nature of the company's processes and previous researches done on the field it is necessary to address some company level issues. Some recommendation on organizational level are presented as well as inclusion of the company's other processes is brought up when necessary, considering the purpose of the project and the thesis. Main focus is on the development process, more specifically on the actions to be taken and considerations to be made during it. In other words, the aim is to ensure systematic consideration of the environmental aspects during each phase of the product development process and to create a framework that supports successful DfE process and practices. Implementation of the suggested practices is not within the scope of the project.

Marketing activities are not within the scope of this study, therefore the focus will be more on the product development phases prior to market release. Some related activities might be brought up but, the phases from pre-study to field trial and implementation of environmental design practices related to these phases are discussed in more detail.

1.4 Methodology

This thesis is conducted as an action research. Action research seeks to solve practical problems occurring in communities, such as companies and hospitals. Action research focuses on one specific case at a time and tries not to give generalized answers. The results are valid only in the defined context where the research is conducted. Action research studies the current practices and aims to change the present way of doing things. In addition to change, co-operation is another essential element of the research method. It is characteristic to the method to involve the people who are being observed into the research process. Action research is iterative and cyclic by nature. It is a process that aims at continuous improvement. Each action research cycle consist of planning, action, observing and reflection phases that are associated to the research. Next research cycle starts from where the previous one ended or targets a new problem detected during the previous cycle. Action research with its cyclic and iterative nature is illustrated in the figure 1. (Kananen 2009, 9-11)

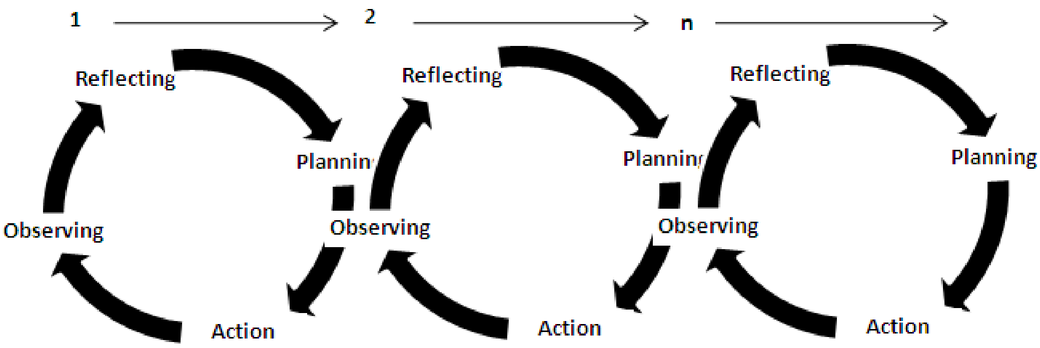

Figure 1. Action research: cyclic process aiming at continuous improvement (adapted from Kananen 2009, 11).

Action research starts from where general qualitative research ends. Data collection and analysis methods used in an action research process are illustrated in figure 2. The figure also demonstrates the research method's relationship to general qualitative research. Action research as a methodology always involves observing as a data collection method, but the methodology does not rule out other ways of collecting data. Methods used for collecting data as well as analyzing the results variy depending on the situation. Even though the method is categorized as a qualitative research method it does not exclude the possibility to use the means of quantitative research, like questionnaires and quantitative measurement methods. In fact, action research is a mixture of different research methods and therefore should rather be described as a research strategy (Kananen 2009, 23-25).

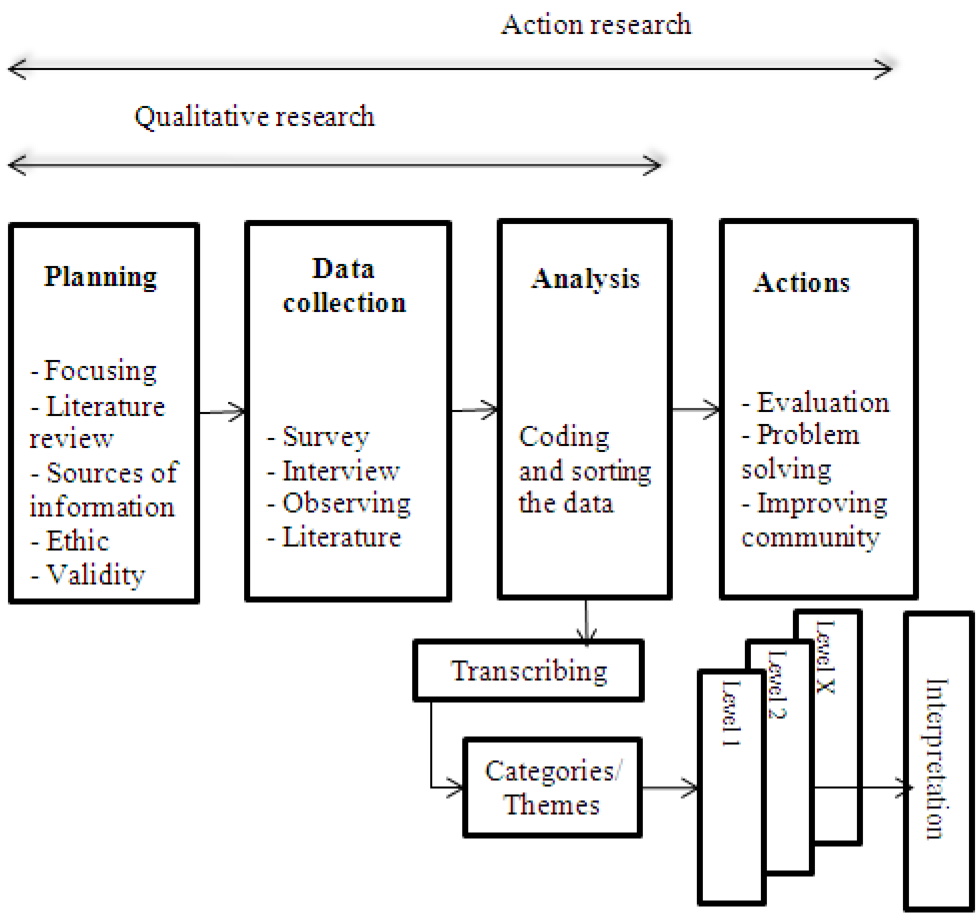

Figure 2. Data collection and analysis methods in action research and strategy's relation to general qualitative research (Kananen 2009, 79).

During the thesis project the author had a chance to work daily among people involved in the product development process. It provided a great opportunity to observe the employees' attitudes, behavior and current practices. This helped to understand the overall framework and problems related to the subject. It also allowed the author to ask specifying questions from development personnel and to hear about further problems as they occurred during the research project.

During the research process also a survey was carried out to find out the customers' requirements regarding the environmental aspects. The survey was sent to 18 people within the organization dealing with the customer requirements in different locations and segments. 13 people responded to the survey, the response rate being 72.2 %. The survey format can be found in the appendix 1. A summary of the survey's results, excluding the open questions can be found in appendix 2. Areas in the need of most urgent focus were determined based on the survey and those aspects were addressed also during the research of the thesis. The presentation of the company and its product development process is written based on the corporate information provided and several discussions and informal interviews with various people involved in the product development process.

1.5 Literature

When discussing the integration of environmental aspects into product development and design process, the range of terminology is vast. It has been argued that *green design* was the original term and over the time this has been replaced with terms such as *ecological design*, *environmentally conscious design*, *ecodesign* or *sustainable design*. These expressions are practically all dealing with the same subject and are more or less synonymous referring to the same practice. Because of the initial purpose of this thesis, which was to develop a Design for Environment guide for the product development process, the term *Design for Environment* will mostly be used. However during the research more versatile terminology was used to find proper literature, studies and research articles done on the field.

Even though the DfE is a relatively young approach there is quite a lot of research done on the field. Several studies approach the subject from the policy perspective or look into the business opportunities involved. Other group of studies focuses on developing proper techniques, tools, metrics and measurements either to support environmental management systems or for the use of designers. The aim was to get the best possible idea of how the DfE practices can be implemented in real life and what are the practical approaches that organizations have employed. In order to do so, studies on the experiences of companies under taking DfE were studied.

Also different standards related to environmentally conscious design were reviewed along with the academic papers. The standard for environmentally conscious design provided by the IEC was found very useful as it addresses many of the same problematic aspects that came up during the project and provided a quite fitting framework of DfE supporting elements. In addition some benchmarking was conducted; people from other companies with more experience on environmentally conscious product development were consulted and studies based on the environmental projects initiated in companies such as ABB, Nokia, Motorola and Vaisala were examined. To large extent the benchmarking study done during the project is not presented in this thesis due to the confidential nature of the information provided by some other companies and their wishes to stay anonymous. This information was utilized for solution generation but was left outside of this thesis.

1.6 Structure of the thesis

This thesis starts with a presentation of the case organization together with a description of the current product development process at the company. In this chapter the main difficulties and problems related to the issue are also described. Chapter three discusses the fundamentals of DfE whereas chapter four deals with the development process level considerations. In chapter five the underlying factors enabling the successful integration of environmental aspects into Vacon's product development process are discussed. Finally, a suggested product development process with integrated environmental considerations is presented in chapter six and conclusion and discussion are provided in chapter seven.

2 PRODUCT DEVELOPMENT AT VACON

In this chapter Vacon and its general product development process are described in more detail. After that the current situation and problems related to the current practices are defined.

2.1 The Organization

The company was established in 1993 in Vaasa when a group of key employees of ABB Industry Oy with knowledge on frequency converters decided to found a company of their own. Since the beginning the company has focused entirely on developing, manufacturing and supplying AC drives and related services. This focus has enabled the company to provide its customers with customized solutions and forefront technology. AC drives can be used to control electric motors or help to generate power from renewable sources like the sun and wind. AC drives are also known by several other names such as adjustable speed drives, variable speed drives, variable frequency drives or frequency converters. They are energy saving products, which improve process performance and decrease environmental load. AC drives are used in all industry segments and in civil engineering. Vacons products are being used in various different applications, from simple motor control applications to more complex systems. Most of the company's sales come from direct sales to the end users. Other sales channels of the company include original equipment manufacturers (OEMs), system integrators and brand label customers. Products are often customized in accordance with customers' requests. (Vacon[1] 2011)

In 2010 the company had revenue of 338 million Euros. Company's operating profit was 28.6 million Euros and ROI of the organization was 27 per cent. In comparison in 2006 the corresponding figures were 186.4 million Euros, 23.1 million Euros and 45.1 per cent. The number of people the company employs has grown from 675 in the year 2006 to be 1339 in the end of the year 2010. During the recent years Vacon and its sales have grown faster than the market. (Vacon[2] 2011) Customer satisfaction and product leadership are the cornerstones for

Vacon's strategic choices. Vacon aims to serve its customers locally where they operate and in order to be closer to its customers the company has established sales offices in 27 countries, created network of partners and continues to expand internationally. Vacon has its research and development (R&D) responsibilities shared between units located in Finland, China, Italy and the USA and 5-7 per cent of revenues have been allocated to R&D in recent years. (Vacon 2010)

2.2 Global R&D Process

Vacon implements the product development model illustrated in figure 3 in all its R&D centers developing new products. The model constitutes of main phases and gates between the phases. Phases are grouped into blue, yellow and orange boxes, each having its main objectives. The meaning of this grouping is also to illustrate the simplified and eased cross-functional communication during the process itself. Between the phases there are gates V0-V6 where it is decided whether or not the project may proceed to the next phase. The organization implements concurrent engineering in its product creation process. This capability of organization to concurrently execute tasks in product creation is the foundation for the agility of the model. Tasks are distributed, roles are defined and competencies are ensured in an early phase of the project. This front loading allows putting more focus on concept creation and validation of the project prior to the detailed development work. This leads to better overall time-to-market, because of better control over the development risks and less iteration needed. (Vacon[1] 2010)

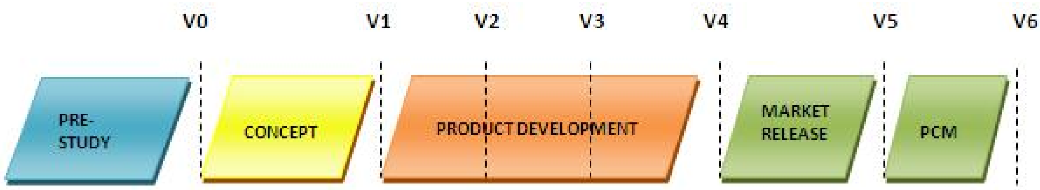

Figure 3. Product development process at Vacon (adapted from Vacon[1] 2010).

2.2.1 Pre-Study

During the pre-study phase the main idea and objectives of the coming product are established, new product initiatives are conceptualized and success criteria for the product are defined. This phase also involves collecting input concerning customer requirements and transforming these into functional requirements and product features. Alternative concepts based on both new and existing solutions are already created, including main dimensions, performance criteria and a 3D mock-up model. (Vacon[1] 2010)

Defining target markets and segments, the business case criteria, basic concepts that need to be developed such as the product and its variations, marketing, technology and production form an important part of this phase. Also a plan for the next phase is created including identifying open questions for concept development and consideration of resources, timeline and criteria for completion. (Vacon[1] 2010)

2.2.2 Concept

In the concept phase the functional requirements are transformed into part, block or discipline specific requirements and priorities are set. Multiple concept alternatives for the product, its variations, production, logistics and marketing are generated. After alternative proposals are evaluated against the requirements set and risks for each alternative are identified, the concept is selected. The selected concept is developed further and a verification plan including type testing, approvals and reliability testing is created. (Vacon[1] 2010)

The objectives of the project should be clarified and the success criteria at each milestone should be set in this phase. Product’s functional specifications are also finalized and categorized and mandatory specifications are frozen. A plan for the resources, tasks and timelines for the development phases is also generated. (Vacon[1] 2010)

2.2.3 Development phase

The orange box which constitutes the development phase involves three stages, design, design completion and field trial. During the design phase a first prototype is created, functional verification of modules is done, and the proto is subjected to a set of tests such as, drive functional test and pre- highly accelerated life test (HALT). At this point the product level specifications have to be set and concepts for production, testing, logistics and services are frozen. (Vacon[1] 2010)

A final prototype is created during the design completion phase. At this stage the prototype is subjected to several different tests, such as functional testing, type testing, acceptance testing as well as HALT and durability testing. Also associated processes, new product introduction (NPI) to production and NPI to aftermarket support (AMS) start. (Vacon[1] 2010)

During the field trial phase pilot versions of the product are delivered to chosen customers, feedback from their experience is collected and analyzed. During this phase the production line as well as the AMS arrangements are finalized. The field trial phase is followed by the market release phase during which the product is launched to the market, volumes are ramped up and product change management (PCM) starts. (Vacon[1] 2010)

2.2.4 Gates

Between each process phase there is a gate review. Project is not allowed to move next phase before the current phase is accepted at the gate review. Vacon implements a 3-step approach to the milestone reviews. At each gate it is assured that the targets set for the phase have been achieved at technical, project and product level. The technical review group constitutes of project’s technical staff and external experts. They confirm that the verification has been done and DfX principles have been obeyed. They also approve the design data and check that the verification results are acceptable. (Vacon[1] 2010)

Project review is carried out by the project’s core team with representatives from all functions. They review the project plan for the next phases, the schedules, the resources and the risk management. They also check the status of the specifications. The aim of this review is to assure a healthy project plan for the next phases. (Vacon[1] 2010)

Product review is conducted by the project's steering group. They compare the results against the business criteria and make sure that the upcoming product fits its purpose. Critical assessment of time to market is conducted and competitive advantages are carefully considered. The intention of this review is to make sure that the product will be successful. (Vacon[1] 2010)

2.3 Current state analysis

Environmental aspects play an important role in Vacon's business. The product itself is environmentally friendly and by making the product as efficient as possible the company aims to create sustainable solutions for the society around. Vacon AC drives represent technology that helps its customers save in energy costs and improve the process control in their business. Approximately 65% of electricity created is produced by burning fossil fuels, such as oil and coal, which leads to creating lot of CO_2 emissions. It is said that approximately 30 % of energy used worldwide is consumed by electric motors and it is estimated that only one tenth of the installed electricity motors are controlled by AC drives. If all AC motors in the world were equipped with AC drives, it could give savings of about 30% in the energy consumption of AC motors. This saving equals to about 10% of the world's total consumption of electrical energy. (Vacon 2008) According to studies the carbon footprint created during the manufacture and disposal of a 250 kW AC drive is already compensated by using it half a day. After that it can be said that the carbon footprint of the device is negative. (ABB 2010)

Based on the survey results these energy saving potentials and consequential possibilities to reduce environmental load are also in the main interest of the customers. Monitoring energy efficiency of the device itself and providing customers with calculations and information on the payback times is very important. However, the survey demonstrated that today customers' interests in environmental aspects of the product are far more versatile. Customers' inquiries regarding to the compliance with different regulations and European Union (EU) directives, such as RoHS, REACH and WEEE are very common during the supplier selection and audits. In addition to these customers are increasingly interested in knowing the detailed material constitution of the drive, including the concentration of certain hazardous substances and chemicals. EU and other policy makers have been active in creating regulations and targets for recyclability for different industries and many of Vacon's customers are also obligated to meet these targets and regulatory constraints. Therefore the customers have been increasingly interested in the recyclability aspects of the drives. In addition, customers have been more and more concerned about the product's environmental impacts throughout its entire life cycle. Some customers have demanded information on the embedded carbon within the product and besides the carbon footprint calculations people dealing with customers have also been asked for environmental product declarations (EPDs).

There is a lot of technical knowledge in the house and skilled people with high expertise in frequency converters and electronics. People are eager to develop better products for customers and serve them in the best possible way. This includes providing the customers with better answers concerning the environmental aspects of the products. Earlier there has been a project aimed at mapping which of Vacon's products are RoHS compliant. Other than that the information regarding the materials and components used is not recorded and monitored on a level that would allow providing detailed information to the customers. After the product is released to the market it is impossible to provide answers because no relevant data has been recorded during the development process and material selections. This is one of the fundamental problems preventing Vacon to meet environmental needs of the customers.

At the moment people involved in the development process are incorporating environmental aspects to the design process on an ad hoc basis. Environmental issues have been addressed as they have come up, usually through customer inquiries. The fact that there is no environmental expertise in the house to support the handling of environmental issues is noted as one of the problems. Highly technically competent engineers and designers do not necessarily possess the relevant knowledge on the environmental aspects of the product. Development personnel's need for in-house guidance and better knowledge on the environmental aspects of the products were identified during the process.

3 DESIGN FOR ENVIRONMENT

In this chapter the concept of DfE is defined based on literature review. The purpose is to put DfE in the context and give an idea of the overall setting where DfE practices take place. The objective is to provide understanding about the issues companies aim to address by the means of DfE initiatives and on the other hand aspects that have an influence on these practices.

3.1 Fundamentals of DfE

Global awareness of environmental problems has increased. The discussion around the environment and the potential hazards to it involves several aspects. In addition to the global warming, which is probably the most pressing issue at the moment, there are aspects such as the depletion of raw materials, water pollution through toxic constituents and the amount of water consumed. In some region exhaust emissions causing photochemical smog, acid rain and transmission of toxic substances are causing severe problems whereas in some other areas the main concerns may be noise, odor and radiation. The traditional way companies have tried to address these issues has been through pollution prevention and waste management. From this approach companies have increasingly moved on to address the potential environmental problems already during the product development process. Companies have started to implement different kinds of DfE programs and ecodesign initiatives. There are various reasons for this change in attitudes and why companies are implementing the DfE approaches. The most common objectives include satisfying the customer demands, complying with the regulations as well as reducing the manufacturing costs. However, first and foremost DfE is a matter of strategic planning requiring long-term perspective and careful analysis of aspects such as future legislative situations and the development of the world around. (Schischke, Hagelüken & Steffenhagen 2009, 2-4; Dahlström & Ekins 2006, 507-508)

The concept of DfE emerged in the early 90’s among academics and a handful of industrial practitioners attempting to incorporate environmental awareness into their product development. One of the most commonly used ways to define DfE is provided by Joseph Fiksel. He describes DfE as “a systematic consideration of design performance with respect to environmental, health, and safety objectives”. The objective of DfE is to enable design teams to create eco-efficient products without compromising other constraints, such as cost, quality and schedule. Among scholars and industrial practitioners DfE is widely understood to be the integration of environmental considerations into product and process design, with a purpose of ensuring that all relevant and discovered environmental considerations and restrictions are integrated into the product development process (Allenby 1994). Many companies have acknowledged the significance of environmental responsibility for their long-term success. They have not only started to apply DfE in their product development, but they have also experienced that by doing this they have a competitive advantage by attracting new customers as well as reducing costs of production. (Fiksel 1993, 3, 91)

DfE as a discipline is a challenge for the engineers and product developers as well as for the entire company. It requires a much wider way of looking at the system. Engineers are faced with issues that are not in the area of their expertise, they have to include considerations that are far beyond the boundaries of the individual company, and the time periods needed to pay attention to are much longer than the usual product-planning periods. (Thruston 1999, 50) Not all environmental issues a company has to deal with can be addressed by the means of product development process. It has been important for companies to learn to distinguish between issues to be addressed at a department level and those that need to be tackled at a company level, such as legislative issues and green marketing activities. (Baumann, Boons & Bragd 2002, 408)

To assist companies in integrating environmental aspects into product development, various guidelines and standards have been developed. International Organization for Standardization (ISO) has created a technical report 14062 - Integrating environmental aspects into product design and development. This technical report describes concepts and current practices related to the topic. The report is meant for the use of organizations of all sizes and types regardless of their location, complexity or the nature of the product they produce. Another relevant standard is created more recently by the International Electrotechnical Comission (IEC). IEC is the international standards and conformity assessment body for all fields of electrotechnology. The IEC 62430 standard specifies the requirements and measures needed to incorporate environmental aspects into design and development processes of electrical and electronic products. The standard defines that the goal of environmentally conscious design is to reduce the adverse environmental impacts of a product throughout its entire life cycle. Usually this involves balancing the environmental features of the product with a number of other factors, such as its cost and quality, as well as choosing methods to meet the regulatory requirements in as environmentally sound way as possible. (ISO/TR 14062: 2002,v; IEC 62430: 2009, 3, 5)

It is practically impossible to establish general rules for how DfE should be practiced in a company or to create a comprehensive list of technical details to pay attention to in the process. The appropriate targets, methods and technical solutions are greatly dependent on the product considered and several variables related to its life cycle. Putting DfE into practice always requires identifying and evaluating the possible effects to the nature the product might have. The effects might be both negative and positive. (Dammert et al. 2004, 7)

3.2 Life cycle thinking

It is argued that the design for environment practices should be based on the concept of life cycle thinking (LCT). The IEC standard for environmentally conscious design for electrical and electronic products and systems defines LCT as “consideration of all relevant environmental aspects during the entire life cycle of products”. The product and its possible adverse environmental impacts should be considered from a wider perspective, not merely with focus on the processes of the manufacturing company. According to LCT the whole life cycle of the product from “cradle to grave” should be considered. The purpose of adopting this more comprehensive way of looking at the product is to gain better understanding of the product’s environmental aspects from raw material extraction to the end of life handling of the product. The idea is to comprehend what sort of environmental load the product causes, in which phases do the most significant impacts occur and how and by whom could these adverse impacts be reduced. (Kärnä 2001, 23)

Considering sustainable consumption and production, LCT is essential. It makes the producers extend their consideration and responsibility beyond the production sites and the manufacturing processes. In the context of environmental design and LCT, the consideration of a product life cycle (figure 4) starts from extraction of raw materials, is followed by design and production, packaging and distribution, product use and maintenance, and through recycling and other possible end-of-life treatment, finishing with the disposal. There are possibilities to improve environmental performance in each stage of a product life cycle. When designing eco-efficient products, the designers should develop products with improved performance in each stage. For designers, more important and beneficial than analyzing all these life cycle stages in extensive details, is to be aware of and understand the relevant environmental issues in each of the stages. (Nielsen & Wenzel 2002, 247; Lutropp & Lagerstedt 2006, 1397; UNEP 2010)

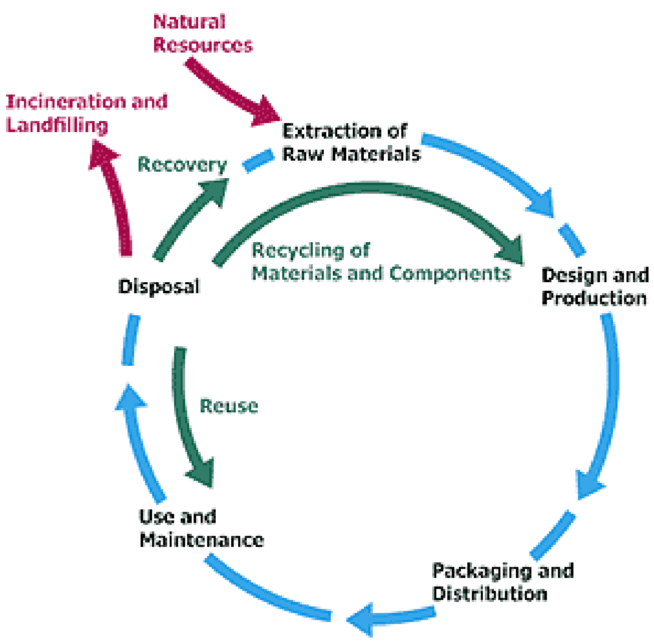

Figure 4. Product life cycle from cradle to grave (UNEP 2010).

LCT and all relevant considerations should be initiated as early in the design and development process as possible. In the beginning of the design process there are more opportunities to make improvements and changes to the product. Challenging is that the possibility to affect the overall environmental performance and the attributes of the product is great, but the information related to the future product is still very limited. Designers' knowledge on the forthcoming product increases towards the end of the development process. However at the same time the possibilities to make changes and include environmental considerations decrease. This paradox of the environmentally conscious design process is illustrated in the figure 5. (Bhander, Hauschild& McAlone 2003, 260-261)

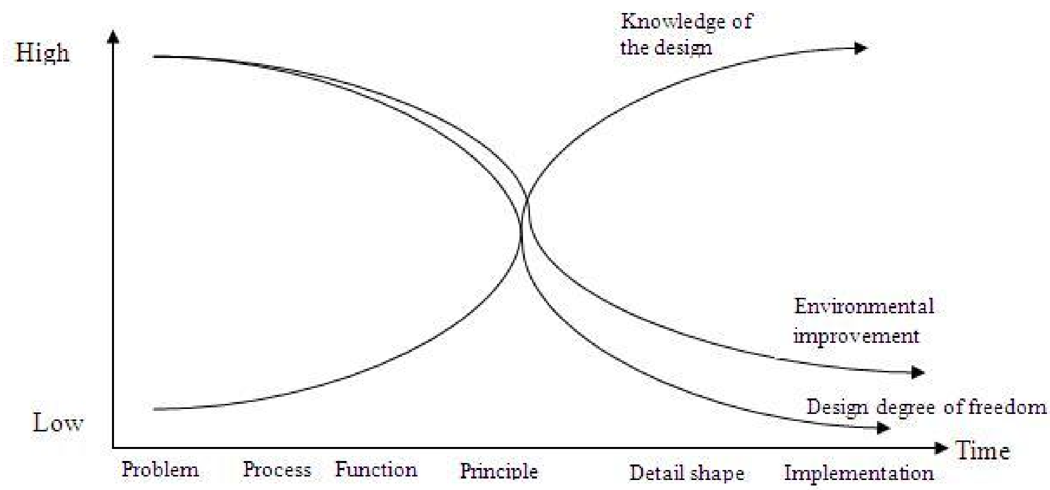

Figure 5. Environmentally-conscious design process paradox (Bhander et al. 2003, 261).

3.3 Company level consideration

A lot of research has been done in the field of environmental product development, but it seems that there has been rather little change in practices of the companies. Companies may have their own environmental department, but when entering through the main door of the company the environmental issues do not seem to be that much of a concern. The fact that the product development might not have been seen in the overall context is an obstacle for true establishing of DfE practices in the companies. The product development's relation with business processes and the company as a whole just has not been established well enough. (Baumann et al. 2002, 409) To tackle this issue, it has been suggested that the DfE objective of minimizing the overall adverse impact of the product should also be reflected in the policies and strategies of the entire organization. (IEC 62430: 2009, 9)

It is necessary to address these objectives on strategy and policy level also because the number of DfE issues that organization has to deal with is huge and not all the aspects can be tackled only by the means of product development and design. It has been distinguished that there are matters that can be taken care of on a department level and those that require wider, company level consideration. The issues and tasks such as relatively simple mechanical and electrical improvements, basic design and engineering issues and proper documentation are easily dealt with on a department level. On the other hand, consideration of stakeholder and shareholder interests, concerns related to regulations, green sales and marketing as well as supply chain management respect to the environmental aspects have been identified to require company level consideration and actions. While engineers are to perform tasks such as selecting the appropriate materials and design products with improved recyclability, the management is responsible for ensuring that different actors like employees and consumers, and component and material suppliers comprehend and achieve the environmental objectives. (Baumann et al. 2002, 409-414; Pujari & Wright 1996, 19-20)

All in all, top management support has been identified as one of the most essential requirements when a company is seeking to improve its environmental performance and integrating environmental considerations into its product development process. Environmentally conscious design is not a separate design activity; rather, it is an integral part of the existing design process including the activities related to the processes of product planning, development and decision-making as well as the creation of policies within the organization. Top management's commitment and interest in environmental aspects has been identified as one of the key drivers of the successful implementation of DfE. (IEC 2009, 9; Jeganova 2004, 24; Baumann et al. 2002, 409-414)

3.4 Environmental policy and stakeholders' requirements

The environmental impact of electrical and electronic appliances (EEA) industry has been a public topic since the early 1980s. There are valid reasons why the EEA industry is being paid so much attention to when environmental protection is in agenda. One of the reasons for this is that electronic products form one of the world's fastest growing waste streams. Electronic products are also relatively complex, meaning that they are composed of a variety of components, parts and materials that are globally sourced and manufactured. A number of materials and substances specific to electronics are known as harmful for humans and nature and some components have already traveled around the world before the end product is even complete. (Schischke et al. 2009, 1; Walsh 2009)

The focus of regulatory concerns has moved from production-related impacts, such as emissions and toxic spills into the environmental burden caused by the products during the entire product life cycle. Keeping up with the constantly evolving legislation often requires a lot of resources and close co-operation with the members of the supply chain. (Kammerer 2009, 2285) Fulfilling the regulatory requirements is a must for a company and the variety of regulatory requirements should be regularly reviewed. The changes that might have an effect to the business should be understood and the relevant ones should then be incorporated to the environmentally conscious product development process as they set some basic ground rules for the coming product and its development process. (Schischke et al. 2009, 1)

The variety of regulations that might have an effect on the processes of the company is vast. In 2003 the EU accepted 2 directives, which are related to recycling of electrical and electronic products and restricting of hazardous substances within the products. In addition to these there is a directive setting requirements for the environmentally conscious design of energy using products. These most common regulatory constraints directly affecting electrical and electronics products are part of EU's integrated product policy (IPP) which promotes producers to improve the ecological efficiency of their products and encourages consumers to make more ecological purchase decisions. Acts similar to IPP have been established also outside Europe. The effects of IPP and related directives are described in figure 6. (Karvonen, Kärnä & Maijala 2006, 17, 31)

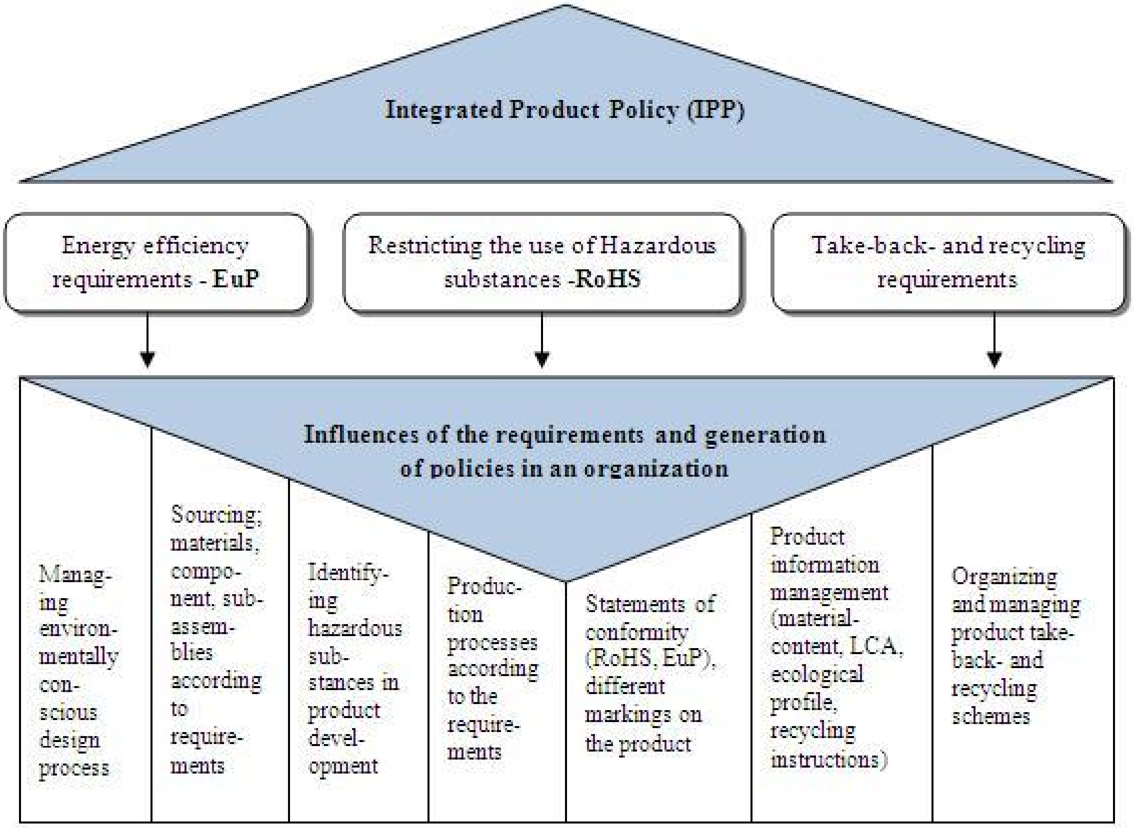

Figure 6. IPPs influences on company's activities (Karvonen et al. 2006, 31).

3.4.1 WEEE

The EU Waste of Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC) aims to reduce the amount of electric and electronic waste generated and to maximize the reuse, recycling and recovery of the waste. Another objective of the directive is to improve the environmental performance of different stakeholders throughout the entire life cycle of electrical and electronic products. It makes the manufacturers, resellers and importers responsible for collection, reuse, recycling and recovery of the products reaching the end of their life. Companies can take care of their producer responsibilities individually or by taking part to a broader producer scheme or organization. Because of the lower cost of the schemes compared to individual models a majority of companies have preferred to join in one of these schemes. (EC 2011; Dammert et al. 2004, 9)

For example Nokia Oyj has acted on the requirements set by the directive by improving the disassembly capacity and recyclability of the products. Furthermore they have developed a take-back scheme for the mobile phones together with telecommunication operators. Whereas the impact of the directive in Vaisala's product development has in practice meant placing a standardized marking label of a waste container with crosses to the products that are released. (Kautto & Kärnä 2006, 23)

3.4.2 RoHS

The EU Restriction of Hazardous Substances Directive (RoHS) (2002/95/EC) restricts the use of hazardous substances in electrical and electronic equipment and thus supports reuse and recycling of electronics waste. RoHS restricts the use of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls and polybrominated diphenyl ethers. According to the RoHS the products placed on the EU markets after the 1st of July in 2006 may not include these substances above the specified maximum levels. Some exceptions do exist and the use of these six substances in some applications is allowed. (EC[1] 2011)

Same sort of legislations have been developed outside Europe in countries such as Korea and China with slight differences. Chinese RoHS for example requires marking all the RoHS compliant parts that are within the scope of the legislation and no exceptions for the use of substances are allowed. The China RoHS also specifies the testing methods for the substances in the electronics and information technology products. Also in United States the Environmental Design of Electrical Equipment Act was introduced restricting the use of the same six substances. They are fairly equal to the EU's RoHS directive concentration levels for 6 substances. (Teknologiateollisuus 2011)

3.4.3 EcoDesign directive

With the purpose of creating a framework for the requirements of Eco design of Energy using products (EuPs) the European Parliament and the Council established the EuP directive in 2005. According to the basic principles of the directive, environmental goals must be incorporated into product design already starting from the product specification. The EuP directive (2005/32/EY) was replaced with the EcoDesign directive on 20th of November 2009. The scope of the new directive is wider than that of the EuP directive. In addition to Energy using products' it includes all energy related products (ERPs). EuPs are products which use, generate, transfer or measure energy, such as, transformers and industrial fans. ERPs do not use energy but they have an impact on energy and therefore they can contribute to energy saving. For example shower and window are in the category of ERPs. The directive is a framework providing a legal context for the development of measures for specific product groups. The directive harmonizes requirements concerning the ecodesign and integration of environmental aspects in the design and development of equipment. (Motiva 2011; EC^2 2011; EC^3 2011)

The Ecodesign directive goes beyond restricting certain hazardous substances. It extends the regulatory requirements set for the ERPs to a much wider scope. However, to ensure that the requirements of customers and other stakeholders are addressed, it is necessary to look beyond the regulations directly affecting the company. Ensuring that the environmental regulations are met requires the organization to:

a) Identify the relevant environmental requirements from applicable regulatory authorities and stakeholders, covering
   - – Relevant product functions,
   - – Relevant life cycle stages,
   - – Relevant environmental aspects of the product,
   - – Geographical scope of the intended market, and
   - – Related activities of the organization;

b) Identify and review the current and new requirements regularly

c) Systematically analyze and document these requirements, identify the affected product functions and life cycle stages as well as the related activities of and responsibilities in the organization and to take the needed actions.
d) Evaluate the new or changed requirements appearing during the design phase, assess their effect on the product and make the necessary modifications.
(IEC 62430: 2009, 18)

3.5 Ensuring the continuous improvement

One of the expectations and purposes of establishing environmental programs is to ensure and encourage continuous improvement of the company's environmental performance. Establishing environmental indicators that are relevant to the environmental objectives of the company is one way to monitor whether any improvement in the performance is happening or not. The choice of an indicator depends on the purpose of use. If the company aims to improve its environmental performance, the indicator introduced should include both physical and chemical characteristics of the product. If the intended use of the indicator is monitoring and external reporting, indicators on environmental aspects and impacts would be proper. (Fiksel 1996, 78; Singhal, Ahonen, Rice, Stutz, Terho & van der Wel 2004, 1-2)

"You can't manage what you can't measure" is a well established fact that applies also to DfE. The ability to evaluate environmental performance in objective and measurable terms is essential considering the effectiveness of DfE. With the assistance of environmental performance metrics it is possible to set goals and monitor the design process and DfE practices. Therefore they are essential for ensuring continuous improvement of the DfE capabilities. In the context of DfE, metrics are parameters used for measuring the design improvements with respect to the environmental goals. For the purpose of setting environmental objectives environmental quality metrics or indicators can be established. Table 1 lists some examples of environmental indicators that were developed for the use of four big mobile phone manufacturers. They were developed for the use of designers wanting to improve the environmental performance, but having a limited understanding of the complex environmental terms. (Fiksel 1996, 76-80; Singhal et al. 2004, 1)

Table 1. Environmental performance indicators (adapted from Singhal et al. 2004, 5).

Life cycle stage	Proposed indicators
Production Phase	• Amount of precious metals, specifically gold • Total area of PWB (surface Area x No. of layers) • Areas of fabricated dies which are processed with the same number of mask steps • Amount of bromine • Area of LCD • Amount of solder paste • Amount of copper used in charger and its cables
Transportation Phase	• Number of components in the phone (No two components are transported in the same package)
Use phase	• Standby power consumption of the charger

The decision on which metrics should be used by the company is sometimes based on the results of detailed LCA studies. The indicators listed in table 1 were developed based on the LCA results which indicated that the PWBs, semiconductors, LCD and solders were identified as having the most significant environmental impact. By studying their physical and chemical aspects further and addressing also the legal perspective the indicators were established. Having the well chosen indicators and metrics in place is important for several reasons. First of all, performance measurement in new product development assures that the product will meet multiple corporate targets, customer requirements and regulatory restrictions. Secondly, the choice of indicators is important since they partly determine what sort of message is sent to the engineering staff responsible for meeting the environmental objectives. The metrics and indicators should be chosen in a way that they reflect the corporate sustainability goals and the evolving customer needs. One of the purposes of the metrics is also to guide the development decisions. (Baumann et al. 2002, 416; Fiksel 2010, 88; Singhal et al. 4)

Motorola is, for example, monitoring the mass of the product, lead content, RoHS substances within the product and recycled material content and has been able to achieve notable improvements in the following aspects. The development of the chosen parameter values between years 2001-2009 can be seen in the table 2.

Table 2. Material Performance: Motorola's best selling Phones and the 2009 MOTO™ W233 RENEW (Motorola 2011).

	Motorola V60 2001	**MOTORAZAR V3i 2006**	**MOTOKRZR K1 2007**	**MOTO W233 RENEW 2009**
Mass without battery (grams)	89,3	79,4	83,5	65,5
Lead content	0,414%	0,0131%	0,0044%	0,005%
RoHS Substances (grams)	0,3699	0,0106	0,0037	0,0034
Recycled material content	7,3%	5,9%	9,2%	19%

3.6 Information and communication

Effective environmental information management is one of the fundamental requirements for an organization trying to improve its environmental performance (Pujari & Wright 1996, 22). Jeganova (2004) identified insufficient internal and external communication with stakeholders as one of the main barriers for incorporating LCT in the product development process. In her study issues such as lack of interdisciplinary cooperation between different departments in environmental issues and the fact that information on customers and suppliers was not summarized or easily accessible created a significant barrier for the inclusion of environmental aspects into the product development process. Elaboration of an environmental communication strategy was suggested to enable continuous communication concerning the environmental aspects of the product.

A communication strategy is an essential part of the process of incorporating environmental aspects into product development. An effective strategy should address both internal and external communication. Internal communication involves providing information to employees on aspects such as the organizational policy, environmental impact of the product, training courses on environmental issues, programs and tools, successful projects or products as well as site-specific impact on the environment. The effectiveness of internal communication can be further enhanced by involving mechanisms to obtain feedback from employees on product design and development issues. (ISO/TR 14062: 2002, 4)

External communication involves providing information on environmental aspects to the stakeholders, such as customers, suppliers and policy makers. Efficient external communication can be an opportunity for enhancing the value and benefits of integrating environmental aspects into product design and development. This communication can involve presenting the product properties such as performance and environmental aspects in addition to the instructions on proper use and end-of-life handling of the products. There are national and international standards created for external communication and exchanging information within the supply chain. For example, the ISO 14025 standard provides principles and procedures for creating Type III environmental declarations. This type of declarations are mainly intend to be used for b-to-b communication and they allow comparisons between products intended for the same function by presenting quantified environmental information on the life cycle of the product. The information presented in the declaration should be based on the LCA data generated following standardized principles and practices. (ISO/TR 14062: 2002, 4; ISO 14025: 2006, 4)

A close customer and supplier relationship is necessary when the company aims to improve its environmental performance. Especially good cooperation with suppliers in environmental programs is important in order to enable the company to have environmentally certified materials and components (Jeganova 2004, 17). Effective supply chain management is seen as an important vehicle of moving the environmental information through the supply chain to the product developers.

The usual way to move environmental information from suppliers to producers is by employing standardized questionnaires via the Internet. (Baumann et al. 2002, 417)

3.7 Conclusion of DfE characteristics

The table below summarizes the issues covered so far and the main points of each aspect.

Table 3. DfE characteristics.

Aspect	Most important points
DfE	• Integration of environmental consideration into the product development process • Objective of creating eco-efficient products without compromising other design requirements • Standards generated, but not possible to create general rules for DfE practices • Linkage with overall context, management programs and other processes of the organization
Life cycle thinking	• Consideration of all relevant environmental influences during the entire life cycle of the product from “cradle to grave” • Looking beyond the productions sites and manufacturing processes • Initiating early in the product development process
Regulatory aspects	• IPP: RoHS, WEEE, EcoDesign • Constantly evolving, regular review necessary • Understanding the influences and keeping up with the development
Environmental Indicators	• Reflect the environmental objectives • Work as a message for developers and other stakeholders • LCA results as a basis • Legal requirements and customer requests considered in creation of the indicators • Enables monitoring and continuous improvement
Information management	• Internal (to employees): - training, policies, product and site related environmental impacts - feedback • External (to stakeholders): - close customer and supplier relationship - product properties and environmental aspects - info on proper use and E-O-L handling

4 ENVIRONMENTALLY CONCIOUS PRODUCT DEVELOPMENT PROCESS

Over 80 per cent of the product's environmental features are determined in the early phase of the product development process and once the product moves from the sketches to the production line the environmental attributes of the product are more or less fixed. Therefore it is important to incorporate environmental consideration already in the design process of a product and to support the development function with tools and methodologies to aid the integration of environmental assessment (Baumann et al. 2002, 412-413; ISO/TR 14062: 2002, v)

4.1 Challenges of integrating the environmental consideration

The following five issues are often named as the main objectives of the DfE process:

1) Efficient use of materials
2) Minimizing the energy consumption
3) Minimizing the use of substances hazardous for humans and the environment
4) Extending the life time of the product
5) Improving the recyclability

However these are not the only objectives product development aims to meet. During each phase of the product development process several aspects are weighted against each other and the final product usually ends up to be more or less a compromise between several different influencing matters. Product's technical, ergonomic, economic and health-related properties, to name a few, have to be taken into account, which creates one of the fundamental challenges for the product development. Environment can never be the only criteria when developing new products. Environmental matters always have to be balanced against other requirements for the product and integrated to the process in harmony with all the other elements. The variety of the elements that developers must balance their decisions between are represented in figure 7. Finding a balance can sometimes be a rather complex task, and doing trade-offs between multiple requirements is unavoidable. Usually requirements having the highest business priority include aspects such as functionality and economy. In the end it does not matter how well environmental issues have been addressed if the customers are not willing to pay for the features and company cannot make profit. (Luttropp & Lagerstedt 2005, 1397; Nilsen & Wenzel 2002, 247)

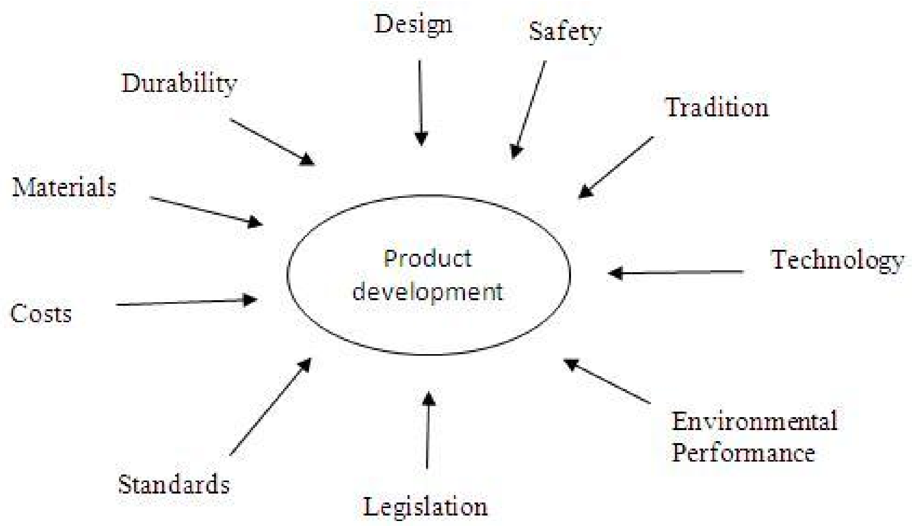

Figure 7. Issues affecting product development (Bhander et al. 2003, 255).

Product developers and designers do not usually have education in environmental engineering and it is rather difficult for them to identify and assess the environmental aspects of the product (Hur, Lee, Ryu & Kwon 2004, 229). Therefore many companies have an environmental engineer or specialist working in product development, supporting the integration of environmental aspects into the product development process. Assistance of the environmental specialists and continuity of the support have been recognized as an important factor in establishing environmental thinking in product development in the long run (Honkasalo, Kautto, Kärnä & Nissinen 2004, 63). However, the experiences indicate that in the long-run it is not feasible or realistic to involve an environmental specialist into every development project. For example at ABB the environmental work used to be conducted by environmental specialists, but today

ABB's project leaders are trusted to have the relevant understanding and capability to make environmentally sound products themselves (Tingström, Swanström & Karlsson 2005, 1380).

4.2 Environmentally conscious development process

An environmentally conscious development (ECD) process or a DfE process should be an integrated part of the company's general product design and development process and not a standalone activity or a side project. Figure 8 illustrates the IEC's view on how management commitment and company policies together with the quality and environmental management systems are the basis for the ECD process. These elements enhanced with LCT create the foundation for the actual ECD process. The actual ECD process utilizes Plan, Do, Check and Act (PDCA) approach. The planning phase starts with an analysis of stakeholder and regulatory requirements and is followed by identification and evaluation of environmental aspects. The do phase includes the actual design and development activities. Check and act involves reviewing the results and ensuring continual improvement. Analysis and evaluation tools together with effective communication and information management are implemented throughout the entire ECD process. The support of these elements and functions is necessary for the success of the process. (IEC 62430: 2009, 13)

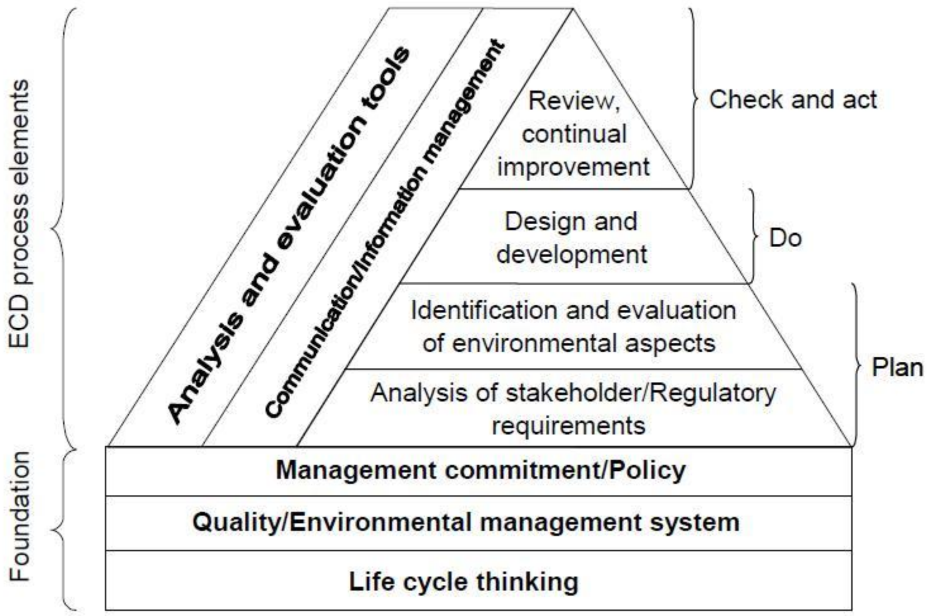

Figure 8. Integration of environmentally conscious design into the management system (IEC 62430: 2009, 13).

The PDCA model is quite widely adopted by companies. Karlsson (2009) in his studies used the model on two different levels. In addition to applying the PDCA process to the actual product development process he adapted it to the management level as well. In figure 9, the PCDA cycle adapted to the general green concurrent engineering model, the Plan Do Check Act phases are described on the DfE management level. An initial product review conducted by the Life Cycle Team together with product planning constitutes the planning phase. The tasks undertaken during the actual product development process belong to the do phase and within this phase there is another entire PDCA process itself. The check and act phases consist of product maintenance and business intelligence as well as tool supervision and system audit.

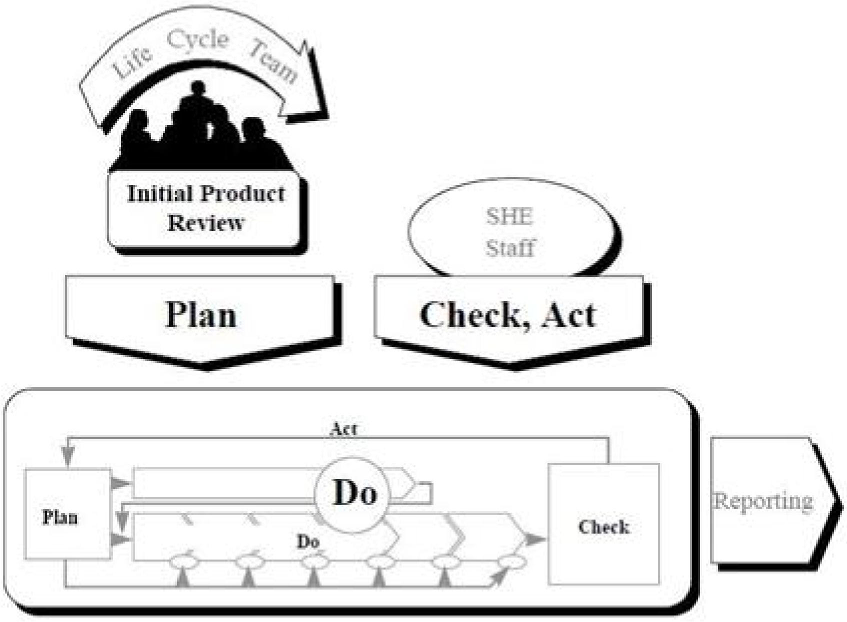

Figure 9. The PDCA cycle adapted to the original GCE model (Karlsson 2009, 44).

Another quite common approach to the DfE process is the implementation of different types of gate models. For example ABB has incorporated sustainability goals into their excising GATE model of product development process. Each gate has a gate owner who is responsible for setting the product specifications and appointing the project leader. The fundamental idea is that between each gate the design project leader makes conscious, documented decisions on how to take care of the sustainability aspects. The project leader is responsible for making sure that all actions for meeting the sustainability targets will be carried out. The progress and the quality of the project will then be evaluated at each gate. Previously ABB used to recommend the use of LCA, but now the project leader has a freedom to choose the best possible tools to be used to support decision making and documentation. This gives greater level of freedom and flexibility, and enables making decisions appropriate for each situation and project. (Tingström et al. 2006, 1380-1381)

ABB's GATE model (table 4) begins with the identification of various different types of requirements and assessment of the most significant environmental impacts that should be addressed during the project. This can be done by streamlined LCA or some other qualitative environmental assessment method. After this, based on the significant aspects the sustainability objectives are set and an action plan for meeting these targets is created. This action plan then serves as a guide through the project. Also possible marketing materials are considered. The sustainability plan is then communicated to the project members and relevant stakeholders and the needed actions are carried out. The Process ends with assessing whether or not the sustainability plan attained the objectives and documenting the result. (Tingström et al. 2006, 1380-1381) Quite similar approach was used by Jeganova (2004) when presenting design process model with incorporated LCT at Alfa Laval.

Table 4. Sustainability actions in ABB's GATE model for control of product development projects (Tingström et al. 2006, 1380).

Gate	Project Stage	Sustainability Action
Gate 0 ↓	Start Project	Sustainability aspects, requirements, assessment and objectives
Gate1 ↓	Start Planning	Sustainability plan
Gate2 ↓	Start Execution	Execute sustainability plan
Gate3 ↓	Confirm Execution	Execute sustainability plan
Gate4 ↓	Start Introduction	Execute sustainability plan
Gate5 ↓	Release Product	Execute sustainability plan
Gate6 ↓	Close Project	Follow-up and documentation
Gate7 ↓	Retrospective Investigation	Follow-up and documentation

4.3 Environmental design tools

There is a vast scale of different types of tools available to facilitate DfE and to meet the environmental targets. The tools vary from simple guides and guidelines to more complex quantitative methods. In addition to the general guidelines, different types of checklists are quite commonly used in companies just starting to include environmental consideration into the development process. There is a fair amount of research done with the focus on developing the right kinds of tools. A wide selection of more sophisticated environmental assessment methods and complex software tools including comprehensive databases, have been developed. Many of these tools are based upon Life Cycle Assessments (LCA). LCA as a methodology was developed little over a decade ago. It is still quite new methodology and its procedures are still evolving. (Honkasalo et al. 2004, 64-65)

Considering the use of any of the tools usually leads to questions on how well does the tool fit into the development process and at what phase it should be utilized. Thinking of the timing for the use of the tool is essential. Since it is commonly recognized that during the conceptual stage the changes to influence on the environmental characteristics of the product are best, many of the tool developers have tried to address this particular phase. However, the designers still find that there is a lack of suitable tools for the early design phase. They have also found using the environmental tools rather challenging and difficult. Therefore the importance of providing the developers with proper instructions on how to use the tools and enhancing the product development process, for example with a multi-disciplinary team with an environmental specialist, is seen at least as important as the tools themselves. (Baumann et al. 2002, 418)

The number of tools available and the amount of academic research dealing with the development of right kind of methods for different settings is a sign that there is a need for proper tools. However, the usability and efficiency of the different tools and methods have also been criticized and they are not being used in the companies that often. Studies have shown that even if the company provides its product developers with new DfE tools as well as knowledge and process models, they hardly ever by themselves lead into more environmentally conscious products and decisions. Alongside with the tools it is recommended to provide the designers and developers with constant support and motivation in incorporating the environmental aspect in their decision making. (Honkasalo et al. 2004, 63-65) According to some studies the existence of tools is not enough and perhaps not even necessary, but the importance of the management and organization has been recognized. (Baumann et al. 2002, 419)

One reason why the tools might not have been used so widely in companies is that the methods are not necessarily generic and they usually require modification prior to the use. This fact that the tools are not immediately applicable might turn into a barrier to the adoption of a technique. DfE tools have to be appropriate from the point of view of the environment as well as of the practitioner, meaning that when choosing the tools it is important to consider the capabilities and know-how of the user, the intended use and the application of the tool. Before implementing any tools, they should be translated into the common language of the company and their suitability with the culture and current practices of the company should be considered. (Knight & Jenkins 2009, 552)

There are many ways to categorize the DfE tools and techniques. Knight and Jenkins (2009) have divided the methods into three broad categories of guidelines, checklists and analytical tools. Guidelines provide little detailed support, but are applicable throughout the development process or for a specific approach such as design for recycling or design for disassembly. Checklists provide narrower but more detailed guidance. They are usually applied at a certain stage of a development process or for consideration of a selected the life cycle stage. Analytical tools provide detailed and systematic analysis of certain phases of the life cycle or the development process. Examples of analytical tools include LCA, environmental effect analysis and material, energy and toxicity (MET) matrix. (Knight & Jenkins 2009, 551)

In addition to LCA, three other techniques, checklist, guidelines and MET matrix, will be briefly presented. Good results have been reported from the use of these tools.

4.3.1 Life cycle assessment

Analytical tools are usually quite comprehensive quantitative methods for evaluating the environmental performance of products. LCA is one of the most important analytical tools. It has been stated that LCA is a very powerful tool for calculating resource consumption and assessing the environmental impacts derived from products and systems. LCA is widely considered the most comprehensive environmental assessment tool for eco-design purposes and it is well supported by standards. Some even consider it as the only correct way to identify the significant environmental aspects of a product. However, LCA has some shortcomings and weaknesses as well. The complexity of the tool restricts its use in the product development process that is usually under pressure to shorten the development time cycle. Therefore incorporating LCA into a design process is not always feasible. Streamlined versions of the method have been developed for quicker assessment of the environmental impacts of a product and a more complex LCA study may be more suited for research separated from the main product development process. (Tuh H. et al. 2005, 229; Baumann, 2002, 416; Bhander et al. 2003, 255)

A full scale LCA has been accused of being a very time and resource consuming process. A large quantity of very detailed data is required for the analysis and most of the information needed is not available until at the very end of the design phase. The problem is that at this point of the process the possibilities to influence the environmental attributes of the product are minimal. Conducting a full scale LCA also requires extensive knowledge and experience on the field, which organizations very often lack. There are also LCA service providers who offer companies environmental consultancy and do the assessments. In an organization starting to produce LCAs for its products it is usually cheaper to do the first assessments with the help of a third party, since this way the investments into the software and databases are smaller and problems related to the LCA process are usually solved quicker. However, obtaining tools, databases and people with relevant expertise is probably more cost efficient in the long run. (Dammert et al. 2004, 38-40)

ISO has established a series of standards ISO 14040-14044 for LCA practice. This is not the only standard available for the purpose, but many of the LCA tools on the market are based on these standards. However, they are still based on different valuations and various assumptions, which all affect the result of the methodology. (Dahlström & Ekins 2006, 518)

4.3.2 MET matrix

A MET matrix (table 5) can be used for evaluating the most significant environmental impacts of the product over its life cycle. In the MET matrix, material cycle, energy consumption and toxic emissions are examined during each life cycle phase. Examination of the material use includes for example evaluation of the raw materials with respect to their scarcity, renewability, re-usability and recyclability. The amount of different materials used in the product and the lifetime of the product and its parts should be considered. When assessing energy consumption, the energy usage during the manufacturing processes and during the use of the product should be examined as well as the energy used for manufacturing the materials and components. Evaluation of toxic emissions pays attention to the hazardous emissions generated during each life cycle phase of the product. The life cycle stages of a product can be divided into as specific stages as necessary. For example, any of the early phases such as production of raw materials, components, sub-assemblies and parts can be divided further into more detailed sub-phases if it is found useful and there are significant environmental impacts related to a specific phase. Also, concerning the disposal phase it is possible to examine the re-use possibilities of the products and components, recyclability of the materials and waste handling options as separate phases.. (Kärnä 2001, 37; Nilsen & Wenzel, 2002, 247)

Table 5 presents an example of the MET matrix analysis conducted for a coffee maker. Information used for the MET matrix can be purely quantitative (for example CO_2-emissions 20 g) or qualitative. It is also possible to use both type of data simultaneously like in the MET matrix example conducted for the coffeemaker. (Kärnä 2001, 37)

Table 5. MET matrix for a coffee maker (Kärnä 2001, 38).

	MATERIAL USE	ENERGY CONSUMPTION	TOXIC EMISSIONS
Acquiring the raw materials	Total weight of the product 1167g	15 components are imported/shipped (energy used for distribution)	PVC manufacturing: remnants of quicksilver into water and waste containing chlorine
Production	Insignificant	Compressed air installation (uses little energy) Testing the device requires 0,05 MJ	Insignificant
Distribution	Package: cardboard (520g), polyethylene (16g), paper (12g) Wooden pallet for transportation	Lorry transport to the shops, ca. 400 km from the factory Diesel as fuel	Emissions from transportation CO_2, NO_X, etc.
Use	Water heated up during 5 years ca. 12775 liters	Device is used ca. 7 times a week Energy required to heat up 1 liter of water is 0,355 MJ	Generating energy causes solid waste and emissions into water and air
Disposal		Lorry transport to landfill (diesel)	Disposed currently to landfill Ca. 20 % of the cardboard is recycled

The MET matrix has been found useful in finding the significant environmental impacts of a product over its life cycle (Knight& Jenkins, 2009, 551). However, in some cases where the environmental impacts of the product are not obvious, quantitative approaches are required (Nilsen & Wenzel, 2002, 247).

4.3.3 Checklists

Checklist can be used as guidance during the phases of a development process. With the help of checklists the general product development objectives, such as minimizing the energy consumption and improving the recyclability can be translated into practical design and development targets. There are many possible applications for checklists. They can be created to support the design of mechanics and electronics, to guide in material and component selection or they can list possible ways to improve the recyclability of the product. A checklist can present the environmental requirements of different countries that need to be paid attention to or they can be used in different points of the process to check that all the required tasks have been conducted. (Kärnä 2001, 116)

In contrast to addressing a single aspect of environmental design or aiming to improve merely one life cycle phase of a product, checklists can also be generated to cover much a wider range of issues. As there are numerous different design aspects to be covered and remembered when optimizing the environmental performance of a product, checklists have been generated to assist the designers. The international standards organization for information communication technology and consumer electronics, ECMA, has created a checklist that provides environmental requirements and various recommendations for designers of information and communication technology and consumer electronic products. Checklist’s purpose is to guide the designers to consider all relevant environmental aspects and to help in documenting the incorporated environmental attributes. The list is very comprehensive and it has been noted that there are not many products to which all the design attributes covered can be integrated. It is not possible to create a checklist that would be appropriate for all electronics products, and for example ECMA’s checklist is principally offered as a template which can be modified by each company according to their own interests. A summarized version of the checklist is provided in appendix 4. The complete version of the list can be found in the ECMA standard 341. (ECMA 341: 2004, 15-30)

5 FOUNDATION OF THE DFE AT VACON

In less than twenty years Vacon has grown from a group of thirteen people who decided to call themselves a company into a corporation that employs over 1300 people and has its operations all over the world. Running business in Vacon today is obviously a different story from what it was back in 1993. Not only has Vacon changed but so has the world around the company. The European Union as well as other policy makers have been active in developing various regulations and directives with respect to environmental protection. Customers are requiring more detailed information concerning the environmental performance of the company and its products. The company has grown rather fast and people have been busy with general business and technical excellence development. Paying attention to environmental aspects to an extent which would be necessary today for a company size of Vacon has just not been the priority number one.

This project is Vacon's first attempt to incorporate environmental consideration systematically into the product development process. It was realized already at the beginning of the project that there were some fundamental issues that need to be addressed before it is possible to go into details of the DfE process itself. These underlying factors enabling the successful integration of environmental aspects into Vacon's product development process are illustrated in figure 10. These elements that will support the future DfE process and practices are discussed in this chapter.

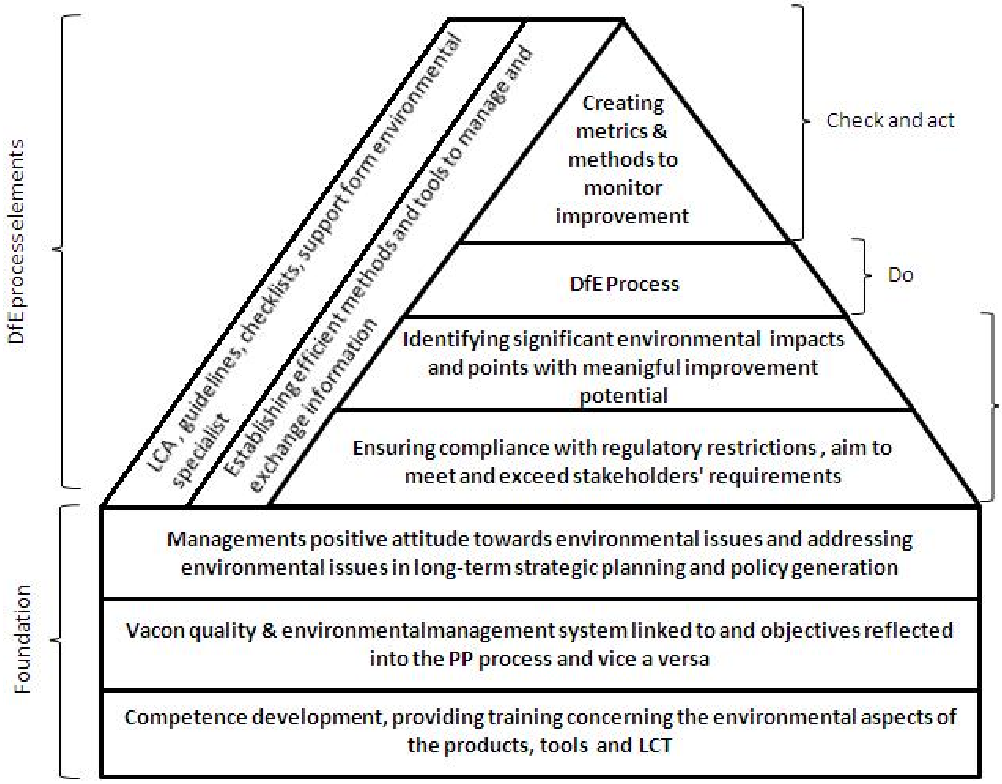

Figure 10. Key issues related to DfE at Vacon.

5.1 Foundation

A successful DfE process is to be based on LCT, supported by management and its objectives are to be reflected in the management system. These factors create a favorable setting where DfE practices can be successfully performed at Vacon.

5.1.1 LCT and capability development

Development engineers may be incorporating LCT to their work on a conceptual level, but no in-house guidance is provided. At the moment there is no sufficient environmental knowledge and there are no resources allocated to the different environmentally related tasks that are to be taken care of. Acquiring an environmental expert in the house can be suggested at this point. This person would be able to provide product development personnel with continuous support and enable them to learn more about DfE. He or she could also carry out and assist in other environment related tasks that have not been carried out before, such as collecting material data from suppliers in an appropriate format, assist in monitoring the development of the legislation and creating necessary environment related documentation to name a few.

However, involving an environmental engineer into the actual process would probably not increase the developers’ knowledge on the environmental aspects or enhance their willingness to incorporate environmental consideration into the development process. Furthermore, in the long run it might not be sufficient even resource-wise to have merely an environmental specialist carrying out environmental work in the product development process. Providing the designers with training concerning LCT, the tools available to aid in DfE and the most significant aspects they need to consider in each life cycle stage of the product is also be recommended. DfE is a new thing for the people in the development process and relevant training would enable the designers to pay attention to the entire life cycle of the product. Training could also include examples of successful environmental design innovations and several ways to improve the environmental performance of the products.

5.1.2 Involvement of other processes

It was noticed during the project that most of the development personnel were not aware of the possible environmental concerns related to product. Neither were they aware of the company’s general objectives to improve its environmental performance. These objectives should be communicated to the entire R&D staff for example in the regularly held R&D info sessions. It was also observed that once some of the people heard about the environmental targets of the company they felt a greater need to start acting and wanted to know more about the ways to address the environmental aspects in the process. Communicated management commitment and positive attitude towards environmental aspects would further increase engineers’ willingness to incorporate DfE practices in their daily work.

The need to link the DfE practices into the bigger context is also clear because of the need of support from other processes and departments. Especially supply chain management as well as enhancing information exchange between different parties within the chain are important in Vacon's case. Vacon does not produce any parts or materials itself. It merely assembles the final products out of materials and components coming from various different suppliers. Therefore the suppliers' products and processes have a great and direct influence on the environmental impact of Vacons' products. The environmental objectives and requirements of Vacon should be communicated to the other members of the supply chain. During the thesis project another project with the aim to increase the quality of the suppliers' processes and their awareness of what Vacon expects from them was launched within the company. This provided a great opportunity to train the suppliers concerning the environmental targets of Vacon and to find efficient ways to exchange the related information. With assistance of other processes such as sourcing, Vacon has a greater chance to make sure that its suppliers comprehend and achieve the environmental objectives. This is necessary if Vacon wishes to reach its own targets.

Responding to customers requirements to provide EPDs for the products would also require input from marketing. However, before starting any green marketing actions and using any additional environmental arguments for marketing purposes, it is important to gain understanding of the environmental aspects of the product within the company and create clear actions aiming to improve the most significant and relevant issues. After gaining solid understanding concerning the environmental characteristics of the product, establishing actions to improve the most significant ones and achieving some documented results, it is safer for the company to start stating the additional environmental excellence of the product.

5.1.3 Relation to the management system

In the survey results many issues came up that are out of the influence of the product development process, issues that would have to be considered on management level or require input and actions from another department or process. For example, some respondents pointed out that it is difficult to give specific answers to customers' questions concerning the environmental policy or sustainability issues, since it is combined with the quality, health and safety policy of the company. These aspects have been thought out in the company, but the documentation concerning the aspects is not sufficient. Only with the commitment and contribution of the top management is it possible for Vacon to enhance its environmental performance. One way Vacon's management can formalize its commitment is to establish particular goals as well as allocate sufficient financial and human resources and time for the tasks needed. The topics that goal setting and action planning could include are listed in table 6.

Table 6. DfE practices supporting actions requested from other processes.

Process	**Tasks**
Sourcing	• Require compliance statements relevant to each project (REACH, RoHS etc.) • Help to collect information on materials and hazardous substances within the products • Include high level of environmental performance into the supplier selection process and require environmental and sustainability management programs to be in place
Marketing / Sales	• Collect feedback and information on environmental requirements of the customers • Finalizing the environmental marketing material for each project
Management	• Establishing targets for continual environmental improvement of products and supply chain management • Defining and communicating the environmental vision and policy more clearly • Defining objectives to ensure legal compliance and reduced adverse environmental impacts of products • Allocating resources and assigning responsibilities, tasks and accountabilities for environmental tasks • Supporting product design and development programs • Organizing/structuring environmental functions and processes for product design and development

5.2 Supporting DfE elements

Whereas the aspects described in the previous chapter create the foundation and are in many ways prerequisite for establishing successful DfE practices in the company, the following aspects support the integration of environmental aspects into the product development process. In figure 10 these issues form the top part of the pyramid and surround the actual DfE process.

5.2.1 Tools

In figure 10 one of the elements supporting the actual DfE process is a proper set of tools. During the project a tool-box was created to help the product development personnel to incorporate environmental aspects to their work. The tool-box includes general guidelines for DfE at Vacon, a MET matrix, a summary of the most relevant regulations concerning Vacon and a few checklists for different uses, such as how to improve the recyclability of a product and aspects to consider during material selections. Product developers need to be familiarized with the tools and trained in their use. In the beginning this could be done with the support of an environmental engineer. In the future each product development person can choose a tool from the tool box that he or she feels is the most suitable for each situation. Also, further studies on the need of tools should be done. For example, developers might find it useful to have a tool to support them in making decisions between different requirements related to material selection.

Before having people with relevant knowledge on LCA and other resources available, it is not feasible for Vacon to start conducting LCA calculations on its own. It is suggested that at this point Vacon should conduct LCA in cooperation with a University or a consultancy company with expertise on environmental matters. The possible LCA providers were mapped during the project. Through this process it is also possible for Vacon to gain knowledge on the LCA process and learn about the proper ways of conducting the assessments on its own in the future. In the long run, if Vacon feels the need to conduct full LCAs for all its products, it is probably more cost efficient to obtain one of the LCA programs and allocate personnel for conducting the assessments.

5.2.2 Information management

In the beginning of the project an insufficient procedure related to environmental information management was identified as one of the key problems. Procedures for efficient information collection, management and exchange should be established. As said earlier, information exchange between different stakeholders, such as customers and suppliers is to be enhanced. Product and component related information is to be stored into the product data management system (PDM) of the company.

Information exchange within the supply chain related to the characteristics of the components, mainly the substances and materials used in them, should be enhanced. First of all, this data is to be required from the suppliers, secondly it has to be stored into the PDM system so that it is available for the relevant people. However, this is not as simple as it may sound. Even the suppliers do not always know exactly what is in their products and they do not have the capability to provide Vacon with detailed information on the materials and substances. Therefore the suppliers would have to be trained on this matter. Based on the information needs of the customers, requirements coming from certain regulations and the general information need for assessing the environmental performance, the following data presented in table 7 should be managed. Establishing procedures for maintaining and updating information is highly recommended.

Table 7. Requirements for information management.

Information needed	Basis	Data collection
Weight & diameters	Customer inquiries Basic product information Logistics	Data sheets from suppliers Material declarations Scale (designers)
Material constitution	Customer inquiries Assessing recyclability and overall environmental impact created EPD	Incorporating more detailed data into component specifications (designers) Material declarations form suppliers when necessary
Amount & location of hazardous substances in the product and components	Customer inquiries Regulations Recyclability instructions and assessments	Material and substance declarations
Energy efficiency	Customer inquiries Future regulations EPD	Current measuring procedures

Compliance statements for the components (RoHS, REACH, WEEE)	Customer requirements Regulations	Material declarations and compliance statements from suppliers
Most significant environmental impacts of the product throughout entire life cycle	Customer inquiries Improvement possibilities for R&D EPD	LCA
End-of-life handling of the product	Customer inquiries WEEE	Study the recyclability of the product, material data needed

At the moment, before establishing more efficient ways to manage environmental information, all the data described above is to be placed in PDM and attached to the component, part, material or product it is related to. The data needed for a full LCA will be specified further during the first LCA project.

5.2.3 Identifying significant environmental aspects

Getting a good grip of the life cycle impact of the product is possible by conducting a full scale LCA to a few representative models of Vacon's products. Based on the previous LCA studies done on frequency converters the environmental impact during usage is by far the most important and making the device as energy efficient as possible seems to be the best way to decrease the overall environmental burden over its entire life cycle. However, the possibilities to increase the energy efficiency of the product are not endless and mapping other areas with true improvement potential such as material and components is important. Because of the lack of resources and knowledge it is suggested to conduct the first LCA with the help of an environmental expert. In the long run company wishes to be able to produce such calculations in-house. Collaboration with an environmental consultant or such should be arranged in a way that it enables the company to learn how to do the assessments on its own in the future. In order to do the calculations themselves, the company needs to acquire software that is suitable for the purpose, a database with relevant information and a person dedicated for carrying out the calculations more or less fulltime.

Customer needs create the foundation for all Vacon's processes and customer requirements have been the trigger for this project. Hence a survey addressing customer needs was conducted to figure out the most significant environmental aspects for Vacon to concentrate on. The survey showed that the main concerns of the customers were related to the energy efficiency of the product. Many of the respondents had also been faced with questions concerning the materials used and the more specific constitution of the drives. Customers were keen to receive more detailed information on materials, components and substances within the product as well as about its compliance with different regulations. Inquiries related to the directives REACH and RoHS are nearly always part of the selection process when a customer is choosing a supplier. Another aspect that customers have been increasingly concerned about is the recyclability of the products. The environmental requirements of the customers can be categorized into 3 groups; Energy efficiency, materials and substances used in the product and the recyclability of the product. These groups form the most important environmental aspects for Vacon to address from the point of view of improving customer satisfaction and they should be among the first issues to address. In addition, in order to improve these aspects, it is also essential to improve the ability to provide customers with information related to these issues.

5.2.4 Aim to meet and exceed regulatory and stakeholder's requirements

The most important directives that directly have or might in the future have an effect on Vacon's processes – RoHS, WEEE and EcoDesign - were presented in chapter 3.4. During the project a summary of the most important regulations that might have an impact on Vacon products was created. Since the regulations and requirements are constantly evolving, regular review of them is necessary. The summary should be regularly reviewed, development of the regulations should be continuously monitored and taking part in the committees generating of related standardization and communicating with policy makers are recommended.

Many of Vacon’s customers themselves have to comply with the regulations specific to their segment, industry or to the countries where they operate. These requirements too are fed downstream to Vacon. Since Vacon has customers in several different segments and various geographical locations, the variety of regulations Vacon has to comply with is vast. For example Vacon itself is not directly within the scope of regulations such as REACH - Restriction, evaluation, authorization of hazardous chemicals, but many of its customers are still interested in the status of the substances within the directive and practices related to compliance with the regulation. In the context of REACH, Vacon belongs to the group of downstream users. Some requirements and guidelines have been established for the companies in this group too. Complying with the requirements created for downstream users and creating relevant compliance statements is necessary. In order to respond to customers’ requirements related to REACH it is necessary to know if any of the substances named in the regulation are present in Vacon’s products. In Vacon’s case this means feeding the requirements further down in the supply chain and requesting the component suppliers for information on compliance with the directive.

Careful studying of the requirements of the intended segment and country is very important. During the project, a number of regulations that Vacon is not directly in the scope of, were identified and descriptions were also included into the summary. The identified regulations are collected in the table 8. The listing is based on the survey results, where the people involved with customers were asked which regulations they have come across with.

Table 8. Regulatory constraints concerning Vacon (Based on Survey results and Summary of regulations created).

Regulative constraint	Description	Note for Vacon
EU RoHS Restriction of Hazardous Substances Directive in electronics products.	The maximum permitted concentrations for Pb, Hg, Cr^{6+}, PBB & PBDE are 0.1% and for Cd 0.01% by weight of homogeneous material.	Similar acts at least in China, Korea, US. The requirements may differ from country to county.
REACH Regulation on chemicals and their safe use Registration, Evaluation, Authorization and Restriction of Chemicals.	Greater responsibility to manage the risks from chemicals and to provide safety information within the supply chain. Substances of interest are listed in Candidate List of Substances of Very High Concern for authorization. List is updated twice a year.	Vacon is a downstream user. Conduct chemical inventory. Possess and study safety data sheets for the substances used. Transfer information within the supply chain.
EU WEEE Waste of Electrical and Electronic Equipment Directive	Makes manufacturers, resellers and importers responsible for collection, reuse, recycling and recovery of product when they reach end of their life. Requirements for manufactures of B2B products differ from those set for manufacturers of consumer electronics	Enhance recyclability through design. WEEE marking on the product. Provide recycling information and instructions for proper disposal. Study the producer responsibilities further. Similar acts initiated also outside EU.
Green Passport The Inventory of Hazardous Materials in ships	Requires ship manufactures to declare specified materials used in the ship construction.	Vacon has to be able to provide the information related to the specified materials and their quantity in the product.

EU directive on batteries and accumulators and waste batteries and accumulators	Directive prohibits placing on the market certain batteries and accumulators with a proportional mercury or cadmium content above a fixed threshold levels.	Vacon products including batteries or accumulators - Removing batteries and accumulators should be easy and safe - Instructions for safe removal to be provided
GOST-R mandatory for a wide range of products in the Russian market	Certification demonstrates compliance with basic safety requirements and the applicable product standards.	Have the documentation ready when planning on placing the product in the market
EcoDesign- directive EcoDesign requirements for Energy Using Products	Sets framework for performance criteria which manufacturers must meet in order to bring their product to the market. Specific requirements created for individual product categories	The requirements for manufacturers of Variable speed drives are under development. Drafting phase

5.2.5 Creating metrics and measurements

Previously other environmental attributes of the product than energy efficiency have not been measured and their development has not been monitored. Energy efficiency of the product is one of the main concerns of the customers. Other environment related aspects of the product that customers have been concerned about and policy makers have been addressing include hazardous substances in the product, recyclability, environmental selection of materials. Some parameters to measure and monitor these aspects should be established. Table 9 presents the environmental aspects and proposed indicators to address it.

Table 9. Suggested environmental indicators for Vacon.

Environmental aspect	Indicator	Information needed
Toxicity	- % of RoHS substances within the product	- Concentration of RoHS substances in each component - Product mass weight
Efficient use of materials	- Weight & volume of a product - Size of PCBs (surface area)	- Weight - Diameters of components
Recyclability	- % of the material that can be recycled - Number of parts that have to be removed before recycling/ scrapping	- Material classes that product constitutes of - Parts containing hazardous substances - Materials with established recycling methods - Materials with no feasible recycling methods - Weight - Number of components
Energy efficiency	- Energy usage in different applications	- Information monitored, no additional requirements

These metrics are suggested for the use of the product development process. Their intent is to enable monitoring and continuous development of the environmental performance of a product, not to evaluate the environmental performance of the company as a whole.

Being able to monitor the following aspects would of course require the relevant material data regarding each part and component to be collected and managed properly. Also, once the first LCA has been conducted for a product, the knowledge on the environmental aspects of the product as well as its problematic parts and materials will increase. Based on those results it is possible to find some other relevant metrics to monitor.

6 SUGGESTED IMPROVED ENVIRONMENTALLY CONSCIOUS DEVELOPMENT PROCESS

Now that the foundation and supporting elements for Vacon's DfE have been established, it is time to go into the actual product development. In this chapter the phases of the proposed DfE process is described in more detail.

6.1 Top level

Identification and consideration of all possible environmental aspects and requirements in an early phase are important as once the specifications have been frozen and material selections have been made, it is nearly impossible to influence many of the environmental characteristics of the product. At least making the required changes will cost time and money. When the specifications for the materials and components are being created, environmental aspects should already be identified and restrictions known. Therefore the entire requirement definition phase as well as the mapping of all the possible influences are very crucial and should be carried out with caution. Vacon already implements front loading to other aspects in its product development process. The same idea of thorough mapping of requirements and a careful development of the concept to meet these requirements should be applied to the DfE process too.

The support of other departments and processes is needed. The designers and developers can create the specifications in a way that they meet the needed regulative constraints, but it is in the hands of the sourcing personnel to make sure that the component suppliers comply with the regulations in their own processes and that they have their own environmental management systems in place. These things should be addressed in the supplier selection process.

The top level of the DfE process is illustrated in figure 11. The suggested product development process at Vacon follows the basic PDCA model to some extent, but in practice it is diffused into the current gate model. A DfE Requirement definition and DfE concept creation form the Plan phase, Detailed DfE is the Do phase and Verify meeting the targets is about Checking and Acting.

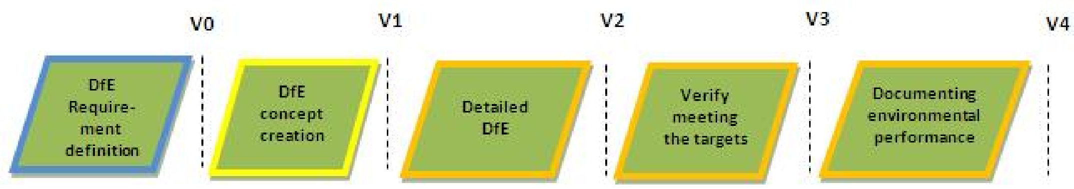

Figure 11. Top level of the suggested DfE process at Vacon.

The process proceeds in line with the general product development process and the gates between the process phases are the same gates that are in the general process. The environmental aspects to be checked between the phases will be added to the general checklist used at each gate. The actual product development process and the DfE process start when a market specification report has been created. In this report the responsible marketing director lists some basic requirements for the coming product. A list of environmental aspects to be checked is added to the gate meetings held between the general product development phases.

6.2 DfE requirement definition

The first phase of the DfE process is requirement definition, which is carried out during and in line with other tasks in the pre-study phase. The tasks carried out and responsibilities at this stage are illustrated in figure 12. First it is important to identify the various different requirements that might have an effect on the project. Product manager is the main person responsible for carrying out this task and pointing out the requirements the coming product has to fulfill. Naturally he will acquire information from various different sources, utilize the knowledge of other people in the organization, consult the different stakeholders and delegate some tasks to other employees. Aspects where the requirements may arise are categorized as follows:

- General customer requirements, such as the energy efficiency of the product

- Requirements specific to the target segment. Vacon's products go to several different industry sectors, which all have their own regulations and requirements that also have an effect on Vacon and they have to be taken into consideration as well. For example, devices going to ships and marine industry will have to be in line with the recyclability requirements defined for the ships.
- Country and region specific regulations and requirements. For instance in some countries customs might require a specific sort of conformity statements or particular labeling and markings.
- Regulatory restrictions set for electrical and electronic products that directly affect Vacon and the company must comply with.
- Also general company policies and environmental objectives are important to take into account at this point. For example general company objectives to reduce CO_2 emissions or general health and safety objectives in manufacturing, such as avoiding certain irritating chemicals.

In addition to the requirements, it is necessary to address the most significant environmental impacts a product has during its life cycle. Identifying these impacts can be done by conducting a MET matrix to a reference product, utilizing previous assessments, such as energy calculations and in the future the results of LCA studies. The goal is to find aspects with true improvement potential, in other words, issues that the company can influence and where it is possible to make a real difference. When generating solutions to improve the most significant environmental aspects, it is necessary to keep in mind the main ideas of LCT, such as not to shift problematic environmental burden from one life cycle stage to another, but to decrease the total environmental burden. The general guidelines for DfE at Vacon include these main issues together with examples of things to consider when the aim is to reduce the environmental impact in each phase. This document can be referred to during the idea generation. When all influential environmental aspects have been recognized and their influence has been assessed and understood, the aspects to work on in the project can be chosen and environmental targets can be created for the selected aspects. These environmental objectives will then be included in the product specification together with other requirements set for the product.

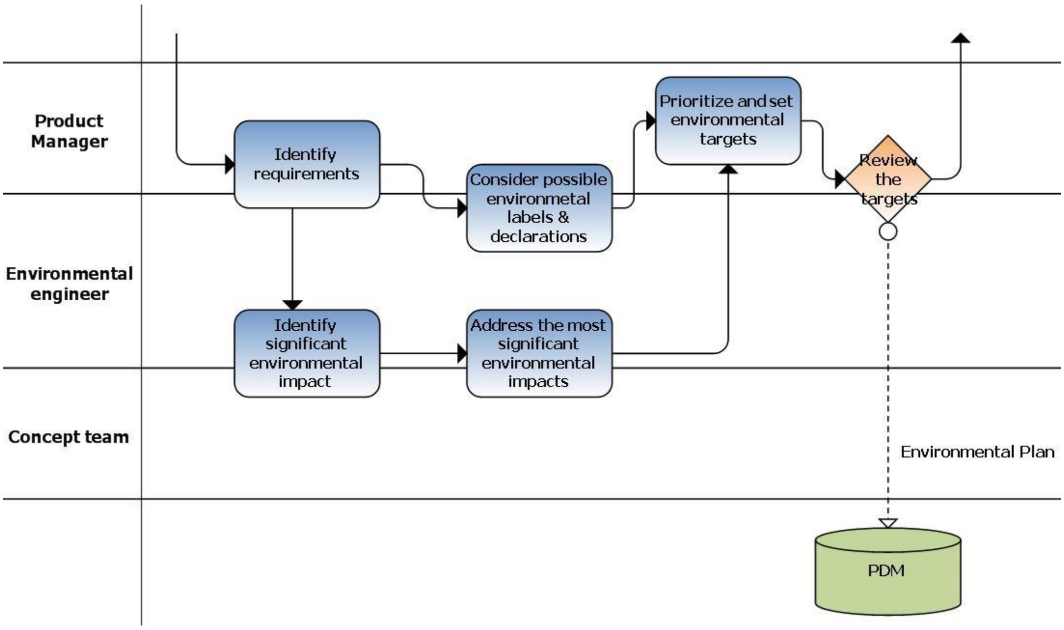

Figure 12. DfE requirement definition.

6.3 DfE concept creation

The actual action plan for meeting the environmental targets is created during the concept phase. The DfE concept creation tasks are illustrated in figure 13. During this phase more specific ideas will be created for meeting the set objectives. The developers will work out technical solutions to meet the environmental targets and compare the possible solutions against other requirements set for the product. At this point DfE checklists as well as Eco Benchmarking can be utilized. Also various certificates, such as conformity statements related to the REACH, RoHS and WEEE directives are defined at this stage. Even though during requirement setting the needed statements might have already been pointed out, it was found suitable to include them as a separate task in the process description, to ensure that the related actions needed are realized. For the same reason it is good to start thinking about the additional environmental information for manuals and marketing material. During concept creation an initial marketing plan will be created and at that point it should also be considered whether an EPD, LCA reports and energy efficiency calculations, for example, are to be created for the coming product.

Now it is possible to define the task and actions needed. The requirements, solutions and information needs are translated into actions and improvement tasks. Things that need to be done in order to meet the targets and people responsible for completing the tasks are defined. Also the parameters and measurements are defined and tasks related to documentation, marketing and other additional material creation are described and an action plan is created.

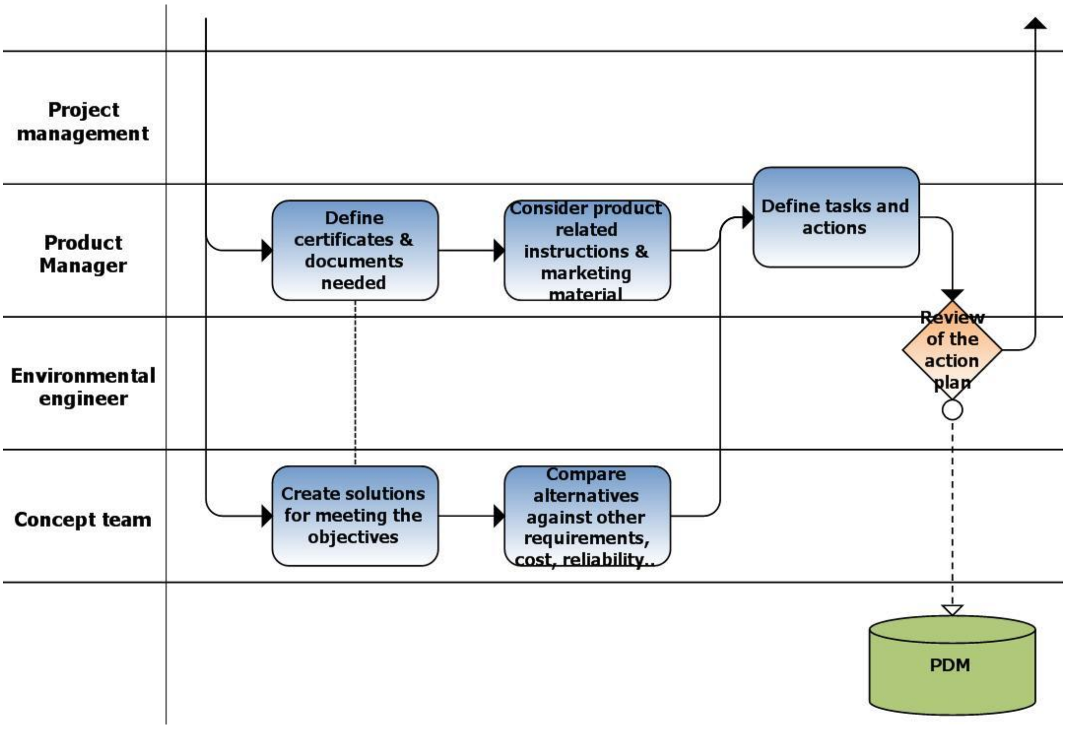

Figure 13. Activities in DfE concept creation phase.

6.4 Detailed DfE

Once the objectives of the project are clear and an action plan for meeting the targets is created, the action plan shall be implemented. The detailed DfE phase is all about carrying out the action plan. The actions will vary from project to project, but the general rules of DfE will always be implemented into the detailed design. The developers can utilize various checklists to support them in their tasks. It is every designer's responsibility to try to optimize the environmental impact. This means that they should find a fine balance between environmental, cost, quality and several other design requirements described earlier and make conscious trade-off decisions. Optimizing the environmental impact requires the designers to remember the main DfE objectives of increasing recyclability, aiming at efficient use of materials, optimizing the life time of the product and designing for the minimum use of restricted substances.

Figure 14 illustrates the responsibility of sourcing. Material data collection begins within this phase and information gained on the material attributes will be utilized in decision making. Requests for material declarations as well as for the needed compliance statements will be sent to the suppliers by the sourcing personnel and filled declaration forms will be stored into the PDM system. All parts will be reviewed and approved with the assistance of an environmental engineer. In the review it will be checked that the components and parts meet the environmental requirements and that all necessary information on the parts is available. At least weight and volume, compliances and material declaration information should be stored into the PDM system once the decision to use a certain component or part has been made.

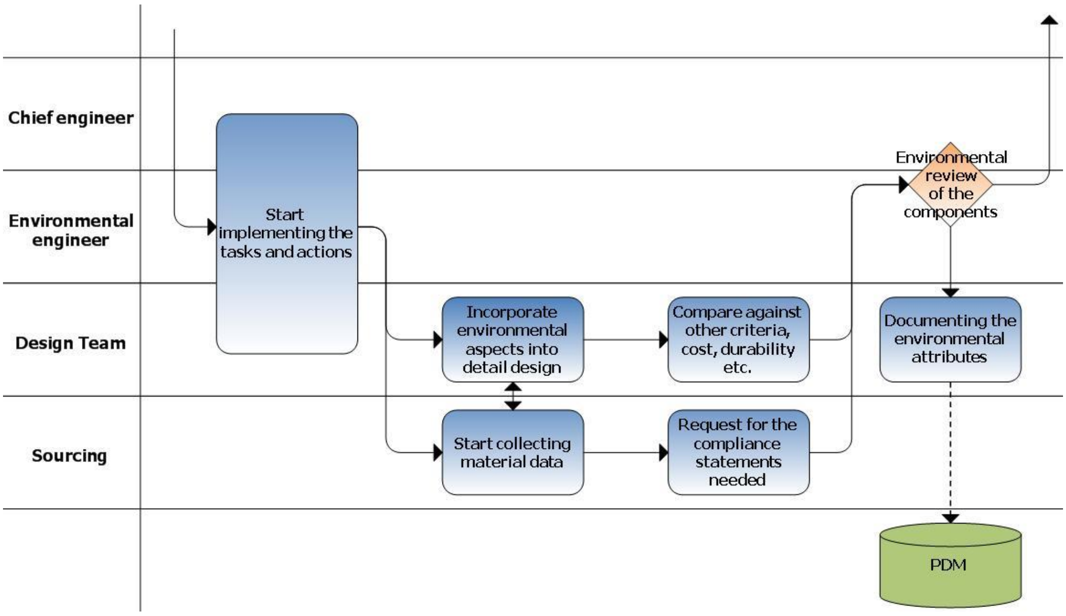

Figure 14. Activities during the DfE concept creation phase.

6.5 Verifying and documenting the environmental performance

During the previous stage it was made sure that environmental considerations were incorporated to detailed design and carrying out the tasks contained in the action plan was started. This is followed by checking that the environmental objectives will be met. It will be ensured that the final compliance statements and material declarations are received from the suppliers. Once all the necessary data has been gathered, the selected environmental parameters and metrics of the prototype will be assessed. The possible metrics are described in chapter 5.2.5. The results will be documented and compared against the objectives set and necessary corrective actions will be made. The Verify meeting the targets phase that is illustrated in figure 15 will end with the environmental review. In the review the product as well as the overall progress of the project will be assessed.

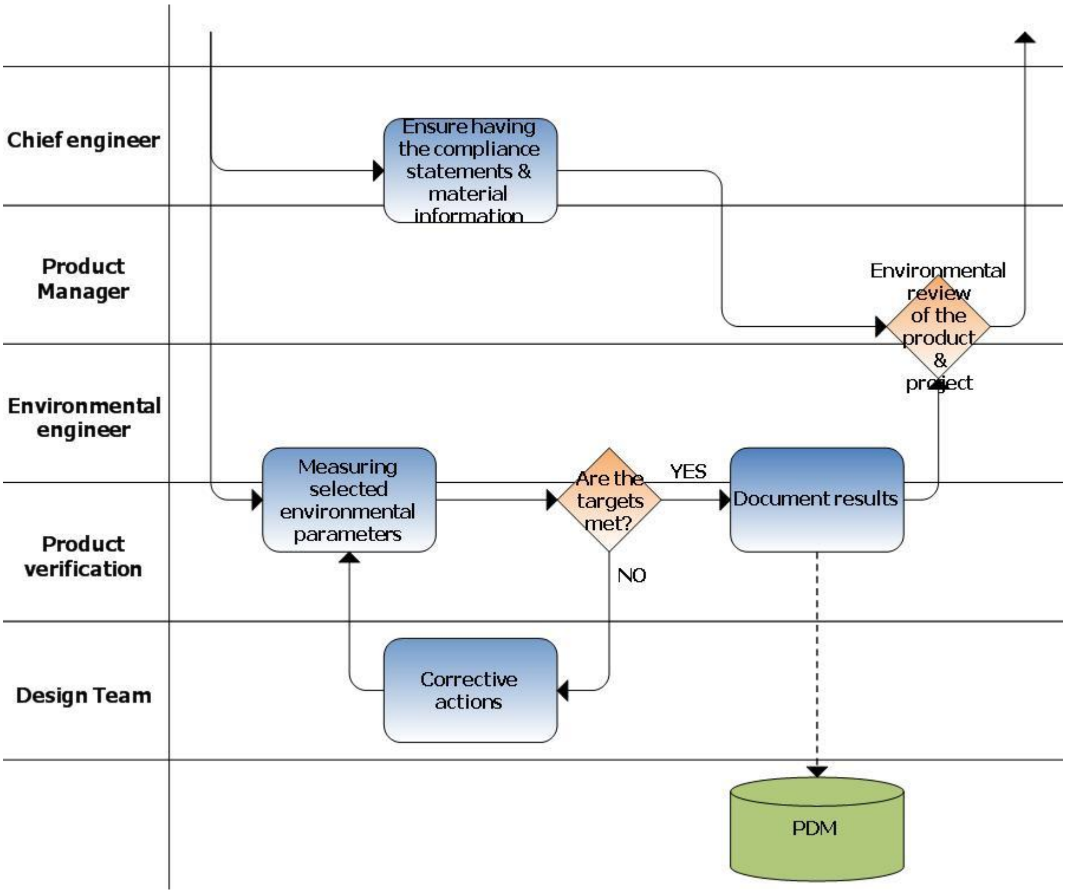

Figure 15. Activities related to verifying that the DfE targets are met.

Verification of meeting the environmental targets should be finalized by the end of the design completion phase. After it has been verified that the targets are met and environmental data is available, the defined documents and statements will be finalized. The documents to be created and the related responsibilities are illustrated in figure 16. The environmental aspects of the product will be presented in an easy to understand and informative form in the EPD. Creating an EPD also requires conducting a LCA to the product. For now the full scale LCA needed to acquire the information need for an EPD will be conducted with the help of an environmental expert. Once the company is able to produce this sort of calculations in-house, the LCA will be carried out during this phase when the environmental characteristics of the product are known to a sufficient extent.

In addition to an EPD, marketing and other additional material, such as recycling and scrapping instructions as well as the necessary conformity statements will be finalized, reviewed and published. Publishing the additional material on the internet is also recommended in order to reduce the use of paper.

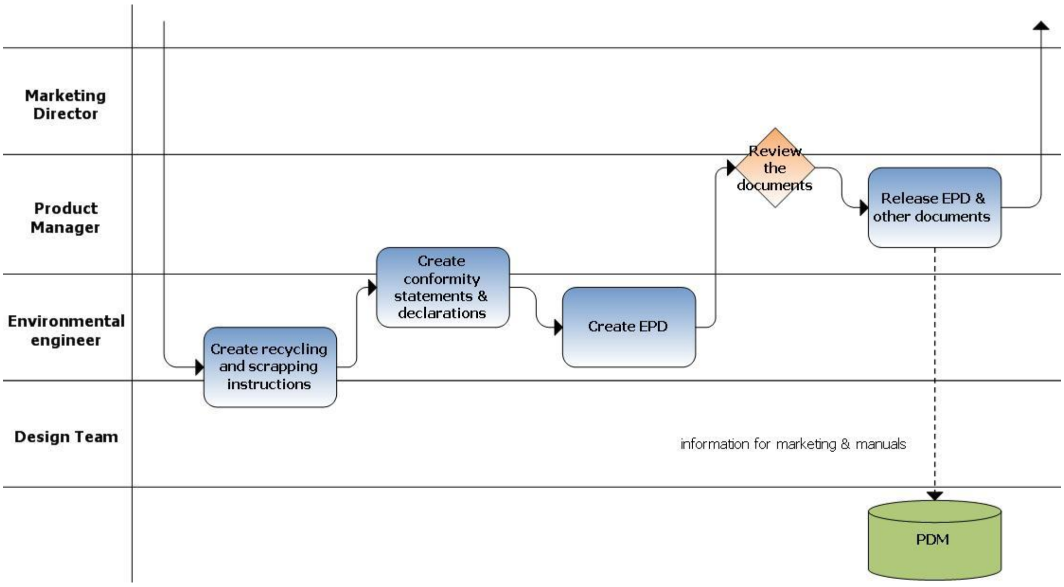

Figure 16. Activities related to documenting the environmental performance.

People involved in the process should have the possibility to give feedback during the process and once the DfE process has been piloted and ran through for the first time, it should be reviewed and the necessary adjustments based on the feedback and project results should be made.

7 CONCLUSIONS

During the last few years Vacon has grown rather fast. Therefore issues that are not directly related to the core business of the company have not always been paid as much attention to as they might have deserved. At the same time in today's world as the company reaches a certain size and global visibility it can no longer ignore issues like environment and sustainability in its processes. Policy makers in Europe and elsewhere, with acts similar to IPP, have also made it necessary for the companies to make environmental product improvements and manage more detailed environmental information if they wish to continue operating successfully in the market and have a reputation as a contributor for sustainability also in the future.

Product development has been identified to have the greatest chance to influence the environmental attributes of a product. It has been stated that even 80 per cent of all the environmental impacts related to the product are determined during the design. A decision to aim to improve the environmental performance by the means of product development is definitely the right one. At the same time it is a rather challenging task as it requires changes in attitudes, in ways information is managed within the organization including updating the IT tools of the organization as well as in the competence development of the R&D personnel. In the end an AC drive is a truly environmentally friendly product and Vacon's solutions are contributing to sustainable development. However, as long as the information collection, management and documentation are lacking neither the negative nor the positive environmental impacts of the company and its products are shared with the relevant stakeholders to a sufficient extent.

7.1 Results and recommendations

The aim of the thesis was to answer to the main research question "How should the environmental aspects be integrated into product development process in the case organization?" by responding to the following three sub-questions:

What are the most important environmental aspects from the case company's point of view?

Vacon is a customer driven company and customers' wishes set the basis for all Vacon's businesses. Customers' concerns related to the environmental aspects are also the most important and urgent issues for Vacon to address. The energy efficiency of the product, its material constitution including detailed data regarding the amounts of various substances of concern as well as the recyclability of the product are the most pressing issues. Just as important as it is to address these issues by the means of product development, it is to create capability to provide truthful information concerning these aspects. Managing the material data efficiently and documenting the decisions and improvements made during the design process are important. These will enable providing information related to the environmental attributes of Vacon's products to the stakeholders once they are released to the market.

In addition to fulfilling the customers' needs, meeting several regulatory requirements concerning the environmental issues that influence Vacon directly or via the customers' requests is just as important. In order to ensure that the requirements set by the directives such as RoHS, WEEE and EcoDesign are met, it is necessary to regularly review the constantly evolving regulations. Whenever possible, it is suggested to participate in the development process of the product-specific requirements and join the working groups creating standards for the EEA industry. As regards complying with different regulations taking more proactive approach and being prepared for the changes is recommended. Changing and developing the regulations further usually takes time and the changes can often be anticipated long before they come into effect. It is easier to make the necessary changes to the products and processes if the company is prepared. The requests of the customers as well as the most relevant constraints of environmental regulation determine the most important and urgent environmental aspects for Vacon to address at this point. Thus, making the product as energy efficient as possible, reducing harmful substances in the products, addressing the recyclability matters of the device and moreover providing meaningful information related to these issues are fundamental.

How can these environmental aspects be addressed in product the development process?

The suggested DfE process with a description of its phases was presented in chapter six. This presentation illustrates the framework for the DfE practices that are to take place in Vacon's product development. Due to several variables related to the process it is not possible to create strict rules and precise process model. The way the process proceeds depends greatly on the development project in question. When a new project is started, already the requirements on the indented target market might require totally different types of actions compared to the previous projects. Therefore the modeled process here works as a framework and gives the product development personnel the freedom to make the best possible decisions respect to the needs of each individual project. The DfE practices proposed in the model are to be performed as integrated tasks during the general product development process of the company. The DfE process is not to be performed as a separate design activity, but side-by-side and simultaneously with other design and development activities.

Integrating environmental aspects already in the beginning of the product development process is essential, since it is easiest to influence the environmental characteristics of the product in the early phases of the process. Making changes in the later phases may result in delays in time to market and consequently to greater expenses. Careful study of the impacts of the various regulatory constraints, customers' and other stakeholders' requirements during the pre-study and concept phases enables addressing all possible needs and meeting the requirements in the later phases of the design process. Systematic DfE is a new area for the R&D personnel and they will face several new aspects related to the materials, regulations, recyclability and the entire life cycle of the product that are to be addressed during the process. Furthermore the development engineers will have to make difficult trade-off decisions, not only between different attributes such as functionality, cost and environmental friendliness of the product, but also between different alternatives having different sort of environmental impacts during the life cycle stages. Making these decisions is not always easy and the solutions are hardly ever unambiguous. The support of an environmental expert, providing designers with guidance and training is vital for successful integration of the environmental aspects into the product development of the company.

The tools created can aid in integrating the environmental aspects and LCT into the product development to some extent. Guidelines and checklists were created to guide the designers to think of the entire life cycle of the product and to provide information on the ways to improve specific environmental aspects such as the recyclability and E-O-L handling of products. Before the results of the first full scale LCA are available, using a MET matrix was suggested in the beginning of or prior to development process to gain better understanding of the most significant environmental impacts related to product. Organizing a workshop to discuss these aspects and exchange points of views would be beneficial for idea generation. These tools might be sufficient when starting to implement DfE practices as they help the developers to address the relevant issues. However, in the future it might be useful to provide the designers with more sophisticated methods and tools. For example, providing designers with computer aided tools to assist them in making trade-off decisions and comparing the environmental attributes of different materials during the development process might be useful.

What are the critical factors to consider in order to ensure successful integration of environmental aspects into the design process?

Critical factors here are the issues creating the foundation for and supporting the successful implementation of the actual DfE process. These were also illustrated in figure 10. First of all it is necessary to gain solid understanding of the life cycle impacts of the product within the company. This greater knowledge related to the environmental characteristics of the product can be achieved by conducting a full scale LCA to a couple of products with the help of an environmental expert. As such, conducting an LCA will not change anything. After getting the results, it would be a good idea to organize brainstorming sessions and workshops with the people with knowledge on different aspects of the product, such as logistics, packaging, materials, regulations, energy efficiency and DfE where they can think about the ways to improve the problematic issues. In addition to the knowledge on the environmental aspects of the product, the product development personnel should be provided with training on LCT and possible ways to reduce the environmental impacts of the products in different life cycle stages.

The commitment and support of the management are prerequisites for incorporating environmental consideration into the product development process. The fact that this project was initiated by the top management already indicates the commitment of the management. However, the rest of the personnel are still not sufficiently aware of the environmental goals of the organization. It is suggested to address these objectives to improve the environmental performance in the strategic choices and targets, and also to communicate these goals to the R&D personnel as well as to the other employees. This will facilitate realizing and understanding the importance of the environmental aspects among personnel.

In order to minimize the environmental impacts of a product throughout its entire life cycle it is necessary to involve the whole supply chain in the process. Open communication allows finding the points where actual improvements can be made. Efficient information exchange and communication with the members of the supply chain is important if Vacon wants to improve the environmental performance of the company and its products. This furthermore relates closely to another critical factor discussed - information management.

Suggestions on the data to be managed and possible places where the data could be collected were presented in chapter 5.2.2. Efficient internal communication is just as important as sharing information with the external parties. Additional environmental information that is also suggested to be managed and shared internally include the environmental policy and the objectives of the company together with information on the site and product specific environmental impacts. As regards external information sharing, creating EPDs for Vacon’s products would be an efficient way to communicate the environmental attributes of the products. However, EPDs should be based on reliable data gained from LCA studies. If the company wishes to create EPDs to all of its products in the future, acquiring one of the LCA software available and developing capabilities to do the assessments in-house is suggested.

In order to make sure that the environmental improvements are made, it is necessary to monitor the environmental performance and the changes made. Therefore, establishing a few well selected environmental performance indicators was proposed. Meaningful indicators work as a message to the personnel and the stakeholders appointing the issues the company considers important and worth monitoring. Moreover, well chosen indicators enable continuous improvement of the environmental aspects. Some suggestions for suitable indicators and related information needs were described in chapter 5.2.5. The recommendations for Vacon based on the results of the thesis are summarized in table 10.

Table 10. Recommendations based on the results of the thesis.

Action
Regulatory and stakeholder requirements - regular reviewing - understanding all the requirements - making the necessary changes in processes and products - taking part to the drafting work and being proactive
Implementing DfE process and practices - LCT as a basis - early integration of the relevant environmental considerations - providing the support of an environmental expert and guidance - mapping the need for additional DfE tools
Acquiring environmental capability and knowledge - training the R&D personnel on environmental aspects, LCT and tools - allocating resources for carrying out environmental work in the company - conducting a LCA to gain greater knowledge on the environmental impacts of the product - learning how to conduct LCAs in house
Information management - external & internal - collecting relevant data from the suppliers regarding the material details and environmental impacts of the components - managing data regarding the company’s own processes and environmental performance, such as energy usage, emissions and carbon footprint - developing IT tools further to support information exchange and material data management

Documentation - Communicating the environmental attribute and performance to the stakeholders - EPD, recycling instructions, both positive and negative life cycle impacts of the product - material constitution of the product
Linking product development and DfE to the bigger context - objectives of DfE and management program reflect each other - creating relevant environmental goals and communicating them to the personnel and stakeholders - involving the entire supply chain and finding points of environmental improvements
Striving towards continuous improvement - establishing meaningful environmental indicators - creating methods to monitor relevant environmental aspects - creating environmental targets and initiating related development projects

7.2 Suggestions for further research

It is recommended to take actions towards improved environmental performance before starting to state the environmental excellence of the company. Companies can easily be accused for false statements regarding the green aspects of the company or its products. However, when actions towards improved environmental performance have been made, they should be documented and communicating these improvements to the relevant stakeholders is worthwhile. Energy saving potential and working towards a sustainable society are relevant aspects of Vacon’s business. Vacon has already made some significant environmental improvements, but these have not been communicated in any specific way. Therefore, further studying of green marketing activities and possibilities as well as relevant environmental labels is suggested. Studying these matters may also lead to further requirements for documentation and information management.

Information management systems within the organization should be developed further. Requirements for the PDM system of the company should be defined more clearly together with the responsibilities related to feeding the information into the system. It is suggested to examine what sort of information is to be collected from the suppliers as well as what are the details the product development personnel should be able to feed to the PDM system based on their own knowledge and designs. Also issues such as at what point of the process the information is needed and when it is to be placed to the system should be thought out. It is especially urgent to develop the PDM system used in the company to support the information management related to the materials and amount of harmful substances within the products.

Collecting and managing detailed information regarding the material constitution of the devices presents one of the major challenges to the environmental work at Vacon. Issues related to collecting material data and creating full material declarations for the company's own products are problematic for several reasons. First of all, not even the suppliers possess comprehensive information on the material constitution of the component they supply or the amount of specific substances within the parts. Sometimes material constitution is classified as a business secret and hence the data is not provided. Therefore even when material declarations are requested from the suppliers, it is not guaranteed that any information on materials will be received. Secondly, the lack of standardized procedures to exchange material data between companies has lead to companies requesting the data in several different forms, ways and on different accuracy levels. Even though some standards have been created by associations such as IEC, they have not been very commonly followed by the companies so far. In addition to following the development of the standardization related to material declarations also efficient ways how these issues have been tackled in other companies should be studied and benchmarked. It is suggested to find a benchmarking partner, operating in a similar type of business environment, with more sophisticated material data collection and management systems.

Material selection is one of the most effective ways Vacon can influence the environmental impacts of the product. Therefore it is also recommended to study the current materials used in the products more thoroughly, define the materials that might be questionable or controversial and look into the possibilities to replace the problematic ones with more environmentally sound alternatives. It is also recommended to study the recyclability of the products a bit further and find out the best possible ways to take care of the products when they reach the end of their working life. Should Vacon participate in a producer scheme or could the company come up with some other more efficient ways to take care of producer's responsibilities?

This research was conducted as an action research. As action research process aims to continuous improvement and has a cyclic nature, the development process should continue. This project covers merely the first cycle of the continuous improvement process. When the suggested DfE process is implemented for the first time, it leads to the next cycle that should lead via observing and follow-up to a revised and improved process. This project was only the beginning of the DfE practices in the company. The development towards an improved environmental performance of the company and its products shall continue.

REFERENCES

Allenby, B.R. (1994) Integrating environment and technology: Design for Environment. The Greening of Industrial Ecosystems, (National Academy Press: Washington, DC, 137–148.

Baumann, H., Boons, F. & Bragd, A. (2002). Mapping the Green Product Development Field: Engineering, Policy and Business Perspectives. Journal of Cleaner Production 10 (5). 409-425.

Bhander, G. S., Hauschild, M. & McAloone, T. (2003). Implementing Life Cycle Assesment In Product Development. Technical University of Denmark 22 (4). 255-267.

Dahlström, K. & Ekins, P. (2006). Combining environmental dimensions: Value Chain Analysis of UK iron and steel flows. Ecological Economics 58 (3). 507-519.

Dammert, T., Kaipainen, J., Kuuva, M., Valkama, J., Väänänen, A. (2004) Ympäristökysymykset ja elinkaariajattelu - Lähestymistapoja sähkö- ja elektroniikkateollisuudelle. Teknologiainfo Teknova Oy. Helsinki 75 pages.

ECMA 341: 2010 Environmental Design Considerations for ICT & CE Products. ECMA International. Geneva. 35 pages.

Ekvall, T. (2002). Cleaner productions tolls: LCA and beyond. Journal of Cleaner Production 10 (5). 403-406.

Fiksel, J. (1993) Design for Environment: The New Quality Imperative. Corporate Environmental Strategy 1 (3). 49-55.

Fiksel, J. (1996). Design for Environment: Creating Eco-Efficient Products and Processes. McGraw-Hill. New York. 513 pages.

Fiksel, J. (2010). Design for Environment: Guide to Sustainable Product Development. McGraw-Hill. New York. 410 pages.

Flick, U. An Introduction to Qualitative Research. (2009). Sage Publications Ltd. 528 pages.

Honkasalo, A., Kautto, P., Kärnä, A. & Nissinen, J. (2004) Tuotepolitiikan uudet tuulet. Suomen ympäristö 739. Helsinki. 117 pages.

Hur, T., Lee, J., Ryu, J. & Kwon, E. (2005). Simplified LCA and matrix methods in identifying the environmental aspects of a product system. Journal of Environmental Management 75 (3). 229-237.

IEC 62430: 2009; Environmentally conscious design for electrical and electronic products. International Electrotechnical Comission. Geneva. 62 pages.

ISO 14025: 2006(E); Environmental labels and declarations – Type III environmental declarations – Principles and procedures. International Standard Organization. Geneva. 25 pages.

ISO/TR 14062: 2002(E); Environmental Management – Integrating environmental aspects into product design and development. International Standard Organization. Geneva. 34 pages.

Jeganova, J. (2004). Product Life Cycle Design: Integrating Environmental Aspects into Product Design and Development Process at Alfa Laval. Malmö. Lunds University. 50 pages.

Kammerer, D. (2009). The Effects of Customer Benefit and Regulation on Environmental Product Innovation. Empirical evidence from appliance manufacturers in Germany. Ecological Economics 68 (8-9). 2285–2295.

Kananen, J. (2009).Toiminetatutkimus yritysten kehittämisessä. Jyväskylän ammattikorkeakoulun julkaisuja 101. Jyväskylä. 141 pages.

Karvonen, M-M., Kärnä, A. & Maijala, A. (2006). Tuottajan ympäristövastuu: Riskienhallinnasta strategiseen suunnitteluun. Edita. Helsinki. 142 pages.

Knight, P. & Jenkins, J. O. (2009). Adopting and Applying Eco-Design techniques: A practitioners Perspective. Journal of Cleaner Production 17 (5). 549-558.

Kärnä, L. (2001) Ympäristömyötäinen tuotesuunnittelu - Opas sähkö- ja elektroniikkateollisuuden yrityksille. Sähkö- ja elektroniikkateollisuusliitto (SET). Tammer-Paino Oy. Tampere. 199 pages.

Le Pochat, S., Gwenola, B., Froelich, D. (2007) Integrating ecodesign by conducting changes in SMEs. Journal of Cleaner Production 15(7). 671-680.

Luttropp, C. & Lagerstedt, J. (2005). EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects. Journal of Cleaner Production 14 (2006). 1396-1408.

Nielsen, P. H. & Wenzel, H. (2002). Integration of environmental aspects in product development: a stepwise procedure based on quantitative life cycle assessment. Journal of Cleaner Production. 10 (3). 247-257.

Pujari, D. &Wright, G. (1996). Developing environmentally conscious product strategies: a qualitative study of selected companies in Germany and Britain. Marketing Intelligence & Planning 14(1). 19-28.

Thruston, D.L. (1999). Engineering Economic Decision Issues in Environmentally Conscious Design and Manufacturing. Engineering Economist 44 (1). 50-64.

Tingström, J., Swanström, L. & Karlsson, R. (2006). Sustainability Management in Product Development Projects – the ABB experience. Journal of Cleaner Production 14 (15-16). 1380-1381.

INTERNET REFERENCES

Schischke, K., Hagelüken, M. & Steffenhagen, G. 2009. An Introduction to EcoDesign Strategies – Why, what and how? [e-document]. Fraunhofer IZM, Berlin, Germany. [Retrieved January 6, 2011] From: http://www.ecodesignarc.info/

Walsh, B. 2009. E-Waste Not. TIME. [e-journal]. January 8. [retrieved April 4, 2011] From: http://www.time.com/time/magazine/article/0,9171,1870485,00.html

Vacon 2008. Saving energy with AC drive – presentation. [Vacon intranet]. Updated December 3rd, 2010 [retrieved January 15th, 2011]. From: Vacon intranet for internal use only.

Vacon 2010. It's all about the attitude - Vacon annual report 2010. [e-document]. Vacon Plc.,Vaasa. [retrieved 17th February, 2011]. From: http://www.vacon.com/Default.aspx?id=461442

Vacon[1] 2010. PP process presentation. [Vacon intranet]. Updated December 3rd, 2010 [retrieved January 15th, 2011]. From: Vacon intranet for internal use only.

Vacon[1] 2011. Vacon history. [Vacon intranet]. Updated January 3, 2011 [retrieved January 3, 2011]. From: Vacon intranet for internal use only.

Vacon[2] 2011. Vacon in Brief. [Vacon intranet]. Updated January 3, 2011 [retrieved January 3, 2011]. From: Vacon intranet for internal use only.

ABB 2010. ABB measures drives' ecological payback. [news release on ABB webpage]. February 25th, 2010. [retrieved April 14th, 2011]. From: http://www.abb.co.uk/cawp/seitp202/7c7bc445cae18753c12576d5003a5170.aspx

EC 2011. European Comission. Recast of WEEE Directive. [In European Comission www-pages]. Updated 2011 [retrieved March 17, 2011]. From: http://ec.europa.eu/environment/waste/weee/index_en.htm

EC[1] 2011. European Comission. Recast of RoHS Directive. [In European Comission www-pages]. Updated 2011 [retrieved March 17, 2011]. From: http://ec.europa.eu/environment/waste/rohs_eee/index_en.htm

EC[2] 2011. European Comission. Eco-design of Energy-Using Products. [In European Comission www-pages]. Updated 2011 [retrieved March 17, 2011]. From: http://ec.europa.eu/energy/efficiency/ecodesign/eco_design_en.htm

EC[3] 2011. European Comission. Sustainable and responsible business, Ecodesign. [In European Comission www-pages]. Updated 2011 [retrieved March 17, 2011]. From: http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/index_en.htm

Motiva 2011. EcoDesign-direktiivi. [In Motiva www-pages]. Updated 2011 [retrieved March 17, 2011]. From: http://www.motiva.fi/taustatietoa/ohjauskeinot/direktiivit/ecodesign-direktiivi

Motorola 2011. Corporate responsibility – Environment. [In Motorola www-pages]. Updated 2011 [retrieved March 17, 2011]. From: http://responsibility.motorola.com/index.php/environment/products/materials/#performance

Teknologiateollisuus 2011. Ajankohtaista RoHS asiaa- vain jäsenille. [In Teknologiateollisuus www-pages]. Updated 2011 [retrieved March 17, 2011]. From: Teknologiateollisuus web pages for members only. Password required.

UNEP 2010. United Nations Environment Programme. Life cycle & resource management. [In UNEP www-pages]. Updated 2010 [retrieved March 17, 2011]. From: http://www.unep.fr/scp/lifecycle/

APPENDICES

APPENDIX 1. Survey respondents

Survey 30.11.2010 - 10.12.2010:

Anton Nurmikoski, Product Manager

Charles Xu Marketing Vacon China

Erkki Talvitie, Regional Business Manager

Jim Lerner, Director of Product Marketing & Management, Vacon Inc. (US)

Juha-Pekka Suomela, Key Account Manager

Jukka Hannuksela, Product Manager

Jussi-Pekka Sampola, Managing Director, Vacon Korea and Corporate Segment Director, Marine & offshore

Kaj Rolander, Product Manager

Mark Gibbons, Sales Enginees, Vacon Drives (UK) Ltd.

Markku Rintamäki, Product Manager

Martin Kopka, Sales Manager, Vacon Gmbh (Germany)

Michael Björkman, Corporate Segment Director, Mining & Minerals

Pekka Haapamäki, Technical Manager, Global Accounts

Peter Hellund, Project Manager, Solution Support

Shailendra Salvi, Managing Director & Country Manager, Vacon drives and controls Private Ltd. (India)

Toni Honkakangas, Product Manager

Thomas Thörewik, Managing Director, Vacon AB (Sweden)

APPENDIX 2. DfE- Customer requirements- Survey

DfE- Customer requirements

1. Customer requirements concerning environmental aspects

1. Has a customer ever required further information concerning the following environmental aspects?

- ☐ Materials used and more specific constitution of the Drives' components
- ☐ Environmental directives and regulations that product complies with
- ☐ Emissions into the water and air during the manufacturing or throughout the products lifecycle
- ☐ Energy consumption during the manufacturing or throughout the products lifecycle
- ☐ Energy efficiency of the product
- ☐ Recycling of the product
- ☐ Energy savings that can be obtained with the use of the product
- ☐ Something else (please specify below)

If you ticked any of the box above, please give further information concerning the issue (eg. who was the customer, were you able to provide the customer with the information needed)

2. If customers have required further information concerning the materials used, what sort of inquiries have they presented?

- ☐ Lists of substances that must not exist in the product
- ☐ Lists of substances and their detaild propotion in the product
- ☐ Lists of directives and standartds the product must comply with
- ☐ Something else (please specify below)

If you ticked any of the boxes above, please give further information concerning the issue.

3. Has a customer ever brought up any of the following directives, regulations and requirements?

- ☐ RoHS (Restriction of the use of certain Hazardous Substances Directive)
- ☐ EDEE (Environmental Design of Electrical Equiement)
- ☐ REACH (Registration, evaluation and authorization of chemicals)
- ☐ WEEE (The Waste Electrical and Electronic Equipment Directive)
- ☐ EuP (ecodesign requirements for energy-using products)
- ☐ Green Passport (for ships)
- ☐ Directive on batteries and accumulators and waste batteries and accumulators
- ☐ IPPC (integrated pollution prevention and control)
- ☐ Your own country or region specific regulation(please specify below)
- ☐ Something else, what?

Please give further information (eg. the country or region of the regulation)

APPENDIX 2 CONTINUES

4. Which issue(s) you consider to be the most important for Vacon to consider to be able to fullfill the customers' expectations related to the environmental aspects?

5. Here you can freely comment on anything that comes into your mind related to the topic or give recommendations.

Done

APPENDIX 3. Survey results

1. Has a customer ever required further information concerning the following environmental aspects?

Create Chart | Download

	Response Percent	Response Count
Materials used and more specific constitution of the Drives' components	83.3%	10
Environmental directives and regulations that product complies with	83.3%	10
Emissions into the water and air during the manufacturing or throughout the products lifecycle	25.0%	3
Energy consumption during the manufacturing or throughout the products lifecycle	33.3%	4
Energy efficiency of the product	**91.7%**	**11**
Recycling of the product	66.7%	8
Energy savings that can be obtained with the use of the product	58.3%	7
Something else (please specify below)	0.0%	0

2. If customers have required further information concerning the materials used, what sort of inquiries have they presented?

Create Chart | Download

	Response Percent	Response Count
Lists of substances that must not exist in the product	50.0%	5
Lists of substances and their detaild propotion in the product	40.0%	4
Lists of directives and standartds the product must comply with	**100.0%**	**10**
Something else (please specify below)	0.0%	0

APPENDIX 3 CONTINUES

3. Has a customer ever brought up any of the following directives, regulations and requirements?

Create Chart Download

	Response Percent	Response Count
RoHS (Restriction of the use of certain Hazardous Substances Directive)	**91.7%**	**11**
EDEE (Environmental Design of Electrical Equiement)	8.3%	1
REACH (Registration, evaluation and authorization of chemicals)	58.3%	7
WEEE (The Waste Electrical and Electronic Equipment Directive)	50.0%	6
EuP (ecodesign requirements for energy-using products)	16.7%	2
Green Passport (for ships)	41.7%	5
Directive on batteries and accumulators and waste batteries and accumulators	8.3%	1
IPPC (integrated pollution prevention and control)	0.0%	0
Your own country or region specific regulation (please specify below)	0.0%	0
Something else, what?	16.7%	2

APPENDIX 4 CONTINUES

APPENDIX 4. Environmental Checklist (adapted from ECMA 341)

	Y/N	Details
General Considerations • Life Cycle thinking design strategy implemented in the organization		
Material efficiency • The variety of materials used in the product has been reduced • The amount of material used in the product has been reduced. • The product contains materials that are considered to have lower environmental impact. • The product contains recycled materials. • The product uses renewable materials.		
Energy efficiency **Power modes and related energy efficiency measures** • Ease of use as related to the selection and operation of power saving features was considered and implemented. • List specific power modes that apply to the product. • Detail significant power consumption modules and plans to reduce their consumption. **General Energy Efficiency measures** • All power saving features of this product is documented. • Information on power consumption in all relevant power modes has been made available to product users. • Applicable voluntary agreements aimed at improving energy efficiency of EEE products were considered and recommendations met. • The effects of improved energy design features have been quantified and communicated to marketing.		
Batteries • All batteries in the product comply with applicable restrictions on hazardous substances and preparations contained in relevant national, regional and international legislation. • All batteries in the product are labeled according to requirements of relevant regional, national or international legislation. • All batteries do not exceed a mercury concentration of 5 ppm by weight. • Information on proper procedures for removal and safe handling of batteries is available in product user documentation. • Information on type and location is available in the appropriate product documentation.		
Emissions • Product has been designed such that chemical emissions are reduced wherever possible and complies with all relevant regulations governing chemical emissions from products. • For a product based on the electrostatic process, chemical emissions (Ozone		

APPENDIX 4 CONTINUES

and VOC) and dust emissions have been evaluated. • Results of the emissions measurement(s) have been made available to product users. • Noise emissions have been evaluated and results of measurement are available.		
Extension of Product Lifetime • The product contains common mechanical packages or common parts or components that are used for multiple models in the product family or in multiple generations of the same product. • The product contains industry standard parts. • The product contains modular components. • The product contains reused components and/or parts.		
End of Life • Separation of parts containing hazardous substances and preparations is possible. • Incompatible materials (including electronic modules) connected to case/housing parts or chassis are easily separable. • The product can be disassembled down to the module level using commonly available tools. • All plastic parts with weight greater than 25 g are marked with the type of polymer, copolymer, polymer blends or alloys in conformance with ISO 11469. • A plan for the disassembly of the product into major modules or sub assemblies has been created and made available to dismantlers.		
Substances and preparations needing special attention • The product complies with the applicable international, regional and national prohibitions on the use of certain hazardous substances and preparations. • Use of substances that require special handling or disposal during the recycling process has been reduced or eliminated. • Appropriate information on parts requiring special handling or disposal has been made available to users and recyclers. • Hazardous substances recorded to be restricted are not present in the product.		
Packaging • The variety and the amount of packaging materials used have been reduced. • The used packaging materials are considered to have lower environmental impact. • The packaging was manufactured using recycled or renewable materials. • The packaging complies with the applicable regulations. • The packaging materials have an appropriate marking.		
Documentation • Instructions for users on how to install, use, maintain and dispose the product is provided. • All applicable product environmental information available for product users is documented according to chosen standard.		