Towards Radical Eco-Innovation

Fabric Care at Electrolux

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"If I have not seen as far as others, it is because giants were standing on my shoulders."

- H. Abelson

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Abstract

Innovations are new, exciting and important in solving environmental problems. This paper looks at such 'eco-innovations' with specific focus on just how 'new' they are to the status quo. 'Incremental' innovations are somewhat new, common and refine what was there originally, while 'radical' innovations are extremely new, rare and introduce something completely different to the situation. It is argued that the bigger the improvement one wants to make in environmental impact, the more radical the eco-innovation must be. This paper uses five diverse case studies of washing machines and dryers at Electrolux to try to identify differences in the process by which incremental and radical eco-innovations are reached. To do this, the paper first looks at why different eco-innovations are pursued. Incremental eco-innovation appears to be based more on the influence of the market and governance, while radial eco-innovation is influenced more by technology and external partnerships. Next, the paper examines how the process is managed, and finds that radical eco-innovations seem to diverge from the typical procedure more than incremental eco-innovations. The paper then looks into who in the firm is involved in the crucial early stages in the process, finding that while Marketing is important in incremental eco-innovations, R&D and Environmental Management appear to be more involved in radical eco-innovations. These findings are discussed in the context of Electrolux Fabric Care Europe to provide selected recommendations as to how the firm might better encourage radical eco-innovations in the future.

Executive Summary

Washing machines in EU15 homes consume 43 500 GWh of electricity a year, which is nearly as much as the country of Portugal (ISIS, 2007a; CIA, 2007). Supplying this electricity involves significant carbon dioxide (CO_2) emissions, contributing to climate change.

Energy consumption during use is the most significant impact of a washing machine or dryer, and manufacturers have made substantial improvements in energy efficiency over the last two decades. However it is widely acknowledged that these gains are beginning to plateau as manufacturers continue to make incremental improvements to the standard washing machine and dryer typologies.

A typical washing machine stays in a European home for 14 years and is not replaced until broken. It is the 40 million highly inefficient washing machines that are 10 or more years old that contribute most to the consumption of electricity (ISIS, 2007a). Yet consumers do not replace working inefficient machines with more efficient ones if they fulfil the same purpose.

An opportunity exists in introducing radically different environmentally friendly solutions to both break the plateauing energy efficiencies of the current typologies, and provide owners of old inefficient appliances an incentive to upgrade to the latest technology. Electrolux considers environmental performance a core competitive advantage, and with its long experience in eco-innovation, is well positioned to introduce such 'radical' eco-innovations. Radical innovations elicit new ways of doing things, substituting the old way, differing from the more common 'incremental' innovations, which are additive and refine the status quo.

In order to better encourage radical eco-innovations, the process by which they are achieved must be well understood. This paper aims to add to this understanding through the analysis of incremental and radical product case studies at Electrolux.

The research question of the paper is:

> *"What are key differences in the process of achieving incremental and radical eco-innovations?"*

Sub research questions ask *why* Electrolux pursued incremental and radical eco-innovations (drivers), *how* Electrolux managed incremental and radical eco-innovation processes (procedures), *who* in Electrolux was involved in the development of incremental and radical eco-innovations (functions) and which success factors suggested by the literature applied in cases of incremental and radical eco-innovations (success factors).

A review of the literature found eco-innovations could be categorised into four types. Category 1 (process and product redesign) entails any improvement of a product within its current typology – an additive, incremental innovation typifying many of the efficiency improvements made to washing machines in recent decades. Category 2 (functional innovation) involves a significant change in the device concept to provide the same function as the device it replaces – a substitutive, radical innovation. Category 3 (institutional innovation) refers to the replacement of products with services – another substitutive and radical innovation. Category 4 (system innovation) is the perhaps the most substitutive and radical, requiring significant changes in the device concept, infrastructure and user learning.

Three washing machines and two dryers were chosen as Product Cases, representing a broad range from incremental to radical eco-innovations. Three of the cases were from Category 1 (incremental), and one was in both Category 2 (functionally radical) and 3 (institutionally radical).

The key observations were that for the three eco-innovations categorized as incremental, either consumers or government were the main driver in the innovation's initiation. The incremental cases also exhibited a greater involvement of the Marketing functions early in the process, while R&D was involved earliest in one of the incremental cases. The development process of the incremental eco-innovations tended to follow the procedure used to manage product development at Electrolux.

The functionally radical eco-innovation did not exhibit a strong external driver, and technology was instead considered to be an internal driver in that case. The development process appeared to conform to the procedure used at Electrolux and R&D was determined to be the most involved function early in the process.

The institutionally radical eco-innovation showed external partners as the strong driver, and its development process differed from the standard procedure. Environmental Management was the most involved function, and a number of ecodesign success factors from the literature were identified in this case and not to the same extent in the others, these were environmental education, environmental champions, and access to environmental specialists.

Important barriers to radical eco-innovation were identified in that legislation is not particularly conducive – and sometimes even counter-productive – to encouraging radical eco-innovation. Another barrier identified was that of Electrolux as an organisation, which is geared towards incremental not radical innovations due to its size and necessary efficiency in mass-production.

Based on the observations and insights gained through the analysis, four recommendations were proposed to encourage radical eco-innovation in Electrolux. These were:

Greater Integration of Environmental Management in the Innovation Process

In order to foster a more positive integration of environmental expertise early in the innovation process it is suggested that Environmental Management functions be integrated more formally.

Reintroducing Environmental Education

Since the first wave of environmental education in the late 1990s, the organisation has made great progress in eco-innovations, but in order to continue this trend it is suggested that environmental education is revisited to provide employees with the knowledge and inspiration to contribute to radical eco-innovations.

Freedom for R&D functions

To avoid potentially radical eco-innovations being stifled by early mismatches with demands from the market, R&D functions may need freedom to develop outside-the-box technologies without the need to verify them with the market too early in the process.

External Collaboration

Due to the limitations imposed by Electrolux's large size and lack of manufacturing flexibility, it may be necessary to look outside the organisation to find vehicles for radical ideas.

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1 Introduction

1.1 Background

Washing machines, alongside cars, refrigerators, televisions and vacuum cleaners, are former luxuries that have become essential consumer durables in the households of developed economies. They are also all products requiring energy during operation, the production of which results in environmental degradation. Innovations in reducing their production cost led to their widespread diffusion and subsequent large aggregate energy use and environmental impact. Efforts to limit this impact while maintaining access to their respective functions of fabric cleaning, mobility, food preservation, entertainment and floor cleaning, also involve innovations. These 'eco-innovations' provide the function with a lower impact on the environment. This paper looks at how different types of eco-innovations are achieved in fabric care major appliances, namely washing machines and dryers.

Your average washing machine has negligible impact on the environment, but with over 140 million of them in EU15 homes consuming nearly as much electricity as the country of Portugal, the environmental implications of the average washing machine are in fact far from negligible. (ISIS, 2007a; CIA, 2007). More than 50 million dryers occupy the same homes, with an annual electricity consumption closing in on that of Ireland (PWC, 2008a; CIA, 2007). Due to the use of fossil fuels in the European electricity mix, a significant amount of carbon dioxide (CO_2) is emitted in supplying this electricity, contributing to environmental problems such as the global issue of climate change. Improvements in the energy efficiency of the European stock of laundry appliances therefore have considerable potential to reduce European emissions of CO_2 and contribute to the EU's commitment to a 20% increase in energy efficiency by 2020 (European Commission, 2007).

The business case for producing energy-efficient appliances has not always been strong, as cost savings do not accrue to the manufacturer but the customer. However, recent years have seen increases in energy prices and environmental awareness, and energy efficiency has received greater attention from consumers in Europe. Demonstrating this point, a recent survey about the most important factor considered when purchasing new major appliances revealed that 'low water and/or energy consumption' ranked first – well above the second-placed 'performance' (ISIS, 2007b). Major appliance manufacturers now claim higher margins and expanding sales of energy-efficient appliances (Electrolux, 2007a; Derrell, 2008).

Energy consumption in the use phase is by far the most significant source of environmental impact from laundry appliances in Europe. While users may influence the eventual energy consumption of their appliance through their behaviour, the efficiency with which the machine completes a typical cycle is determined by its design. A series of decisions by marketers and engineers determines the appliance's energy efficiency long before the product is launched on market, and the ramifications of those decisions will be felt for the duration of the 14-year average lifetime of a European washing machine (ISIS, 2007a). The design stage is therefore a crucial leverage point in reducing the environmental impact of these products.

Over the last two decades laundry appliances have seen incremental improvements in energy efficiency resulting in washing machines today that consume 60% less energy than they did 20 years earlier (Electrolux, 2007b). However it is widely acknowledged that these gains are beginning to plateau as manufacturers continue along a technical asymptote within current typologies (Bygge, 2006). This has been noted for washing machines (CECED, 2006) and also for tumble dryers (PWC, 2008a) with the exception of the heat pump dryer which is discussed as a case later in the report. As essentially all manufacturers have now reached the same levels of energy efficiency, environmental performance in this area has turned from a competitive advantage into a commodity.

The combined effect of a 14-year lifetime and significant improvements in energy efficiency over the last to decades is a multitude of old and inefficient appliances in European homes. A full quarter of European washing machines are estimated to be over 10 years in age (ISIS, 2007a). The environmental benefits of replacing these old appliances with the latest most efficient models would be enormous (CECED, 2006), but consumers typically wait until an appliance breaks down before replacing it.

Electrolux is one of the largest manufacturers of major-appliances globally and is considered an industry leader in environmental issues. The company perceives environmental performance as a core competitive advantage, which rests on their ability to continuously introduce environmental innovations. In order to reach new levels of energy efficiency and maintain their competitive advantage, Electrolux must look to develop truly innovative new solutions and break from the technical limitations of current typologies. Such changes are known as ‘radical’ innovations, which elicit new ways of doing things and differ from the typical ‘incremental’ innovations, which essentially improve the current situation. Because such innovations lead to environmental benefits they are termed ‘eco-innovations’.

The argument for radical eco-innovations in major appliances for laundry is particularly strong, as perhaps only radically different solutions to consumers’ laundry needs may be able to persuade households to replace old inefficient appliances before they actually break down. Radical eco-innovations could therefore lead to potential win-win situations with greatly reduced environmental impact and increased revenues for Electrolux.

Innovations can be considered as both processes and outcomes. The process refers to the actions involved in achieving an innovation as an outcome (i.e. a radically new product). In order to better encourage radical innovation outcomes, the process by which they are achieved must be well understood. This paper aims to add to this understanding through the analysis of incremental and radical product case studies at Electrolux.

1.2 Problem statement

The problem statement consists of two parts, one representing industry and the other academia.

With regard to industry and specifically Electrolux, the problem is defined as “*A necessity to overcome the diminishing marginal efficiency improvements in major laundry appliances and maintain a competitive advantage in environmental performance*”. It is proposed that this could be achieved through radical eco-innovation, which is consequently the topic of this paper.

The second problem relates to academia and is defined as “*A perceived lack of empirical research into the process by which radical eco-innovations are achieved* ”. This paper attempts to add to the literature through its analysis of case studies at Electrolux.

1.3 Purpose

The purpose of this study is to provide a better understanding of differences in the process of achieving incremental and radical eco-innovations. This allows selected recommendations to be made on how Electrolux might better encourage radical eco-innovation.

1.4 Research Question and Objectives

The research question for this paper asks:

> *"What are key differences in the process of achieving incremental and radical eco-innovations?"*

The main research question is divided into four sub-questions:

i. *"Why does Electrolux pursue incremental and radical eco-innovations?"*

   This variable is termed Drivers.

ii. *"How does Electrolux manage incremental and radical eco-innovations?"*

   This variable is termed Procedures.

iii. *"Who in Electrolux is involved in achieving incremental and radical eco-innovations?"*

   This variable is termed Functions.

iv. *"Which of the success factors suggested in the literature are evident when Electrolux achieves incremental and radical eco-innovations?"*

   This variable is termed Success Factors.

In order to answer the main research question, two research objectives must be met:

1. Categorise the case studies into incremental and radical eco-innovation outcomes

By categorising the eco-innovation outcomes into a range from incremental to radical, the independent variables are identified. These can be used to analyse the dependent variables, which are determined in Objective 2:

2. Identify differences in the process by which the product case eco-innovations were achieved

The differences in processes refer to the four sub-questions outlined above. These are the dependent variables, which change when an independent variable changes, i.e. when looking at different eco-innovation outcomes. The dependent variables of Objective 2 are compared with the independent variables of Objective 1 to answer the research question.

1.5 Scope

The scope of the research is limited to the European market for laundry appliances, and to the Fabric Care (laundry) division of Electrolux Major Appliances Europe, part of the Electrolux Group. Where applicable global functions in the organisation are also covered.

Primary data sources are limited to Electrolux. Secondary sources do not look into other manufacturers to provide analysis by benchmarking as it was reasoned that due to Electrolux's position as an industry leader, benchmarking would provide limited benefit.

1.6 Structure

The paper first explains the methodology used, before giving an overview of relevant literature. The analytical framework is developed and the cases are presented, with a Base Case of Electrolux Fabric Care Europe providing context for the five Product Cases. The analysis follows, after which a discussion section covers opportunities and barriers before the conclusions and recommendations section.

2 Methodology

2.1 Project Initiation

The author initiated the project, and Electrolux was approached because of a desire to base the thesis on the management of eco-innovation at a large and industry-leading consumer durables manufacturer. Contact was first made with the department for Environmental and European Affairs, who accepted the proposal and thereafter acted as the central point of contact. The thesis project began with an idea to map flows of information leading to eco-innovation and determine directions for further analysis from there. After initial exploratory interviews the research topic evolved to focus on incremental and radical eco-innovation as a process.

2.2 Research Design

As mentioned above, the research had an exploratory purpose in its first stage, where the initial literature review was carried out and unstructured in-depth interviews were conducted with key Electrolux employees. This stage helped to refine the research topic and identify potential variables. Exploratory research is flexible and allows the researcher to gain an understanding of the situation and seek new insights (Robson, 2002).

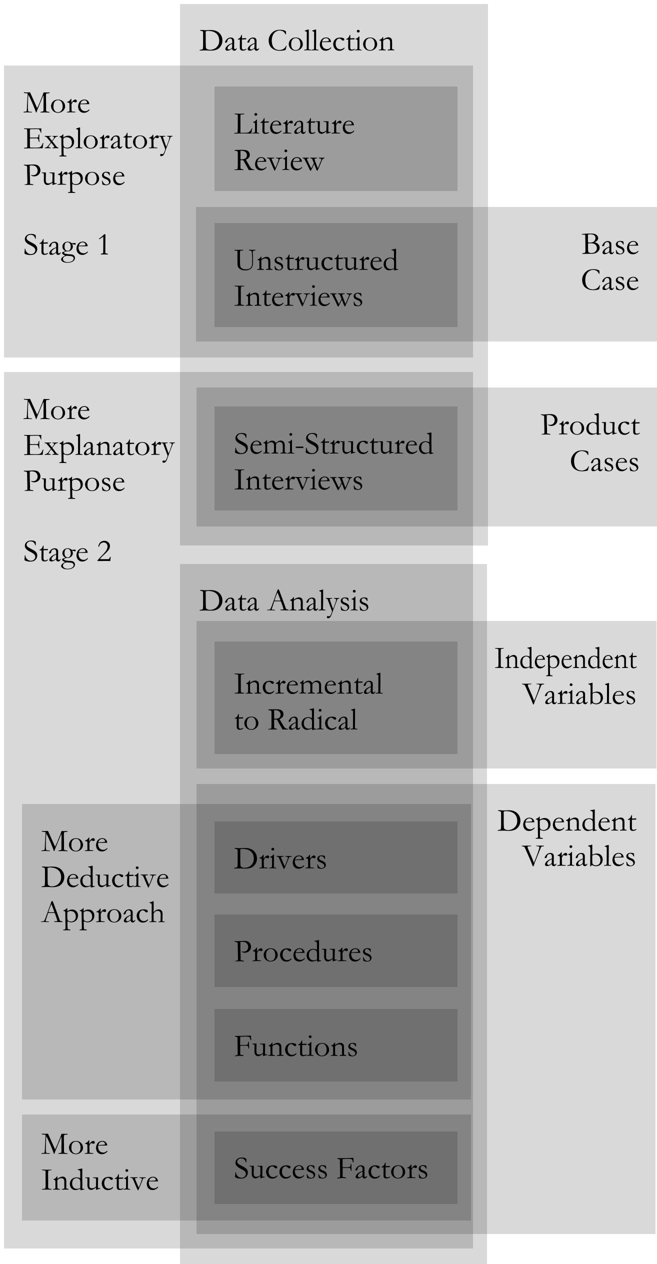

Figure 2-1 Methodology Outline

As a suitable topic for more structured research emerged, the purpose changed. The second stage in the research aimed to answer the research question by identifying relationships between the independent variables (incremental and radical innovation outcomes) and dependent variables (drivers, procedures, functions, and success factors) that were identified in the exploratory stage. It may appear more logical to term the process variables (drivers, procedures, functions and success factors) as independent, and the outcome variables (incremental and radical innovation) as dependent, as the outcome is obviously dependent on the process. However, this study does not look to follow the chronological order of events, but instead to work from the known, independent variables (classification of innovation outcomes into incremental and radical) to learn about the unknown, dependent variables (which drivers, procedures, functions and success factors lead to which outcome). Saunders et al. (2006) refer to this type of research purpose as Explanatory, where causal relationships are established between variables. The research had therefore evolved from a more exploratory to a more explanatory research purpose along the sliding scale between these two types of research, without being a textbook example of either.

2.3 Case Studies

The research strategy chosen to determine the variables was that of Case Studies which are said to suit the investigation of a phenomenon in its natural context (Robson, 2002), such as that of a company. Multiple case studies were conducted which allowed the investigation of various combinations of independent (incremental and radical) and dependent variables (drivers, procedures, functions, and success factors). Multiple case studies are said to facilitate greater generalisation in analysis and broaden the applicability of results (Yin, 2003).

The case studies were conducted in two parts, the first is referred to as the Base Case and covers Electrolux Fabric Care Europe in general terms to provide context for the second part, which involved multiple cases and is referred to as the Product Cases. Five such Product Cases were conducted and it is the information in these cases that is categorised and analysed to met the research objectives and answer the research question.

2.3.1 Product Case Selection

The Product Cases were selected from the same product division within Electrolux to provide a range of related examples of eco-innovations, from incremental to radical (the independent variable). The choice of radical examples was limited due to their rarity. Criteria for selection was simply that the product was eventually commercialised and had some form of positive environmental aspect to its design. The number of five was chosen to achieve a sufficient range of combinations between variables, but to avoid the sacrifices in data quality that might result from the trying to cover a larger sample in the limited time available.

2.4 Data Collection

The data collection consisted of a literature review and in-depth interviews.

2.4.1 Literature review

The literature review was exploratory and gathered information from: Journal articles and books, public materials from Electrolux and the large appliance industry, and confidential Electrolux materials.

The most utilised sources were journal articles and books. Relevant sources were found by searching databases, and through the citations of other articles. Sources were generally from the fields of Innovation and New Product Development, or Eco-Innovation and Ecodesign. The main topic of the paper is the process of radical eco-innovation and much time was spent attempting to find previous research on that specific topic. Due to the lack of success in finding such articles it is assumed a gap in the literature exists. The author's reasoning behind the apparent gap is presented in Section 3.2.2.

Materials from Electrolux and the large appliance industry, whether confidential or public, were used to gain an understanding of the industry and its direction, and to comprehend Electrolux in terms of its organisational structure and the way it manages the innovation process.

2.4.2 Qualitative Interviews

Initial interviews were unstructured and exploratory, aiming to gain an understanding of the Base Case and identify potential Product Cases. Once Product Cases were selected semi-structured interviews were conducted, asking various interviewees the similar questions about the same five Product Cases to identify differences among the four dependent variables.

In all, 21 separate in-depth interviews were conducted within Electrolux with a total of 19 interviewees. Some interviewees were interviewed more than once, and some interviews involved more than one interviewee. The majority of interviewees were from the upper management of their functions and all major functions involved in the product development process were represented, most by more than one interviewee. The first 12 interviews could be roughly categorised as being more exploratory and unstructured, while the remaining 9 were more explanatory and semi-structured.

Initial interviews were organised through the designated contact person at Environmental and European Affairs, with later interviews facilitated through the recommendation of subsequent interviewees.

Ten of the interviews were in person and the other 11 by telephone, with interviews averaging around 45 minutes in length. All interviews were recorded and later typed up as selected transcriptions and detailed notes. The notes from the interviews were then sent by email to the interviewee to verify the information gathered. A full list of interviews is provided in the Appendix as Table 12-1.

2.5 Data Analysis

Stages in the process of data analysis can be described as the categorisation of data, 'unitising' of data, recognition of relationships, and development and testing of hypotheses (Saunders et al., 2006).

Data from interviews was first categorised by case, with selections of text from the interview notes gathered under headings in a master document. The data was further categorised into determinants of the independent variables (incremental and radical aspects of the eco-innovation outcomes), and dependent variables (drivers, procedures, functions and success factors from the literature) observed in each case. The data was 'unitised' in the form of one respondent having said a certain case was in a certain way, i.e. that consumers were a strong driver.

The recognition of relationships between the variables was approached differently for different variables. The relationships between the independent variables and the first three dependant variables of drivers, procedures and functions were approached in a more deductive way, while the relationship between the independent variables and the fourth dependant variable of success factors was approached in an more inductive way.

The more deductive approach to the first three dependent variables means that they are compared with a predetermined theory as to how the variables should relate with one another (Saunders et al., 2006). A deductive approach favours research topics that are well covered by the literature with ample pre-existing theories that can be tested. In this study, there was a perceived lack of literature specific to eco-innovation as a process, and instead literature was used from the more established field of New Product Development (NPD). The reasoning behind NPD's application to radical eco-innovation is described in Section 3.2.2. While there were various similarities, the literature borrowed from NPD did not cover full spectrum of radical eco-innovations. This lack of appropriate literature did not allow a purely deductive approach to be taken, and instead the approach could be considered to be simply more deductive than inductive on the sliding scale between these two approaches.

The method of data analysis used in this more deductive approach is similar to that of Pattern Matching (Yin, 2003), which involves suggesting likely outcomes of a dependant variable (i.e. different drivers) based on changes in an independent variable (i.e. a more radical innovation outcome). In this study some cases could be compared directly with the literature while others could not. While comparisons with the literature were made, the use of non-eco-innovation-specific literature and its incomplete coverage of all cases lead the author to not make specific hypotheses. Hypotheses are a feature of purely deductive approaches.

The more inductive approach to the fourth dependent variable means that instead of applying a theory to test the relationship between variables, the relationship is observed and a theory is developed from the observations (Saunders et al., 2006). Inductive approaches suit research topics not well covered by the literature. Ecodesign success factors are in fact well covered in the literature, but not with regard to incremental and radical eco-innovation where there is a gap. Therefore, a more inductive approach is used to develop understanding as to which success factors apply to incremental and radical eco-innovation processes.

The relationships between variables are tested using matrices. These matrices combine the independent variables (Objective 1, incremental and radical) and the dependent variables (Objective 2, drivers, procedures, functions and success factors) in order to answer the Research Question – *What are key differences in the process of achieving incremental and radical eco-innovations?* The analytical framework is presented in Section 4.

2.6 Limitations

Limitations to this study manifested in primary and secondary data collection and in the analysis.

In collecting primary data the prime limitation was access to interviewees. Electrolux is a large company and for each product case the person with the most information about a specific variable changes. For a more thorough investigation of the cases, further interviews would have to be undertaken. For one of the cases the person with the most information had in fact left the organisation, making the full picture harder to achieve.

In the secondary data collection, searches of the literature were hampered by the large variety of terms by which the concept of eco-innovation can be called. This may have led to relevant literature being overlooked. An overview and partial classification of the various terms used in the literature is provided in Section A in the Appendix.

The analysis has limitations in the fact that only five cases were analysed and for some categories of eco-innovation radicality a single case was used to base the analysis upon. This limits the degree to which findings can be generalised, a problem compounded by the diverse nature of the cases. While results may not be able to be generalised, the different insights gained from the analysis of a very diverse range of cases has its own merits. With a greater number of cases, better triangulation of findings would be possible and more substantial results would follow.

3 Literature Review

This section provides an overview of existing literature on eco-innovation in product development. Using innovation literature as a starting point, this review looks at eco-innovation both as an outcome, and as a process leading to that outcome. Innovation as an outcome refers to the actual innovation, be it a product, service, or otherwise. Innovation as a process refers to the sequence of events leading to that innovation (Berchicci, 2005).

3.1 Eco-Innovation as an Outcome

This section defines innovation and eco-innovation, and explains its incremental and radical forms.

3.1.1 Eco-Innovation Defined

Eco-innovation is a form of innovation, and innovation is the introduction of new things, which could be tangible products or intangible processes, markets or organisations (Schumpeter, 1939). Innovation has been recognised as an important factor in maintaining a competitive advantage in the marketplace (Drucker, 1985) and has had significant attention in the literature. In understanding innovation an important distinction must be made between innovation and invention. To put it simply, invention is the creation of something new, and innovation the utilisation of that invention (Schon, 1967). In the context of a manufacturing company this utilisation generally refers to the invention's development, manufacturing and diffusion in the market. A discovery confined to the laboratory remains an invention (Garcia & Calantone, 2002). Inventions and innovations are often undertaken by different organisations or fields and may be greatly separated by time (Rennings, 2000). Rosenberg (1974) provides a classic example of innovation, in steam-powered ships: While compound steam engines were patented in 1781 (the invention), it wasn't until 100 years later that the technology saw adoption to and diffusion amongst ocean-going vessels (the innovation).

Eco-innovations are essentially innovations with the added criteria of having contributed to a reduction in environmental impact. They were originally defined as *"new products and processes which provide customer and business value but significantly decrease environmental impacts"* (James, 1997). An important consideration here is that of which environmental impacts are decreased. An eco-innovation may decrease impacts from a life cycle perspective, but due to rebound effects may even result in an increase in aggregate environmental impacts. A common example of a rebound effect is that of increased fuel efficiency in cars leading to cheaper operating costs and an increase in use.

Rennings (1998) identifies three specialities of eco-innovation. Firstly that there is a double externality; all innovations create spill-over effects or positive externalities, but eco-innovations differ in that they develop products and services that themselves create positive externalities (by reducing environmental impact compared to existing products and services). Secondly he points to the 'regulatory push-pull' effect resulting from the double externality; governments often try to encourage eco-innovation in light of the public goods provided by its positive externalities. Thirdly he refers to the importance of social and institutional innovation in eco-innovation, citing the importance of the Montreal Protocol in the phase-out of CFCs.

3.1.2 Incremental and Radical Eco-Innovation

As mentioned above, innovations involve new things, and the degree of 'newness' of an innovation has been widely classified in the literature. In classifying how new an innovation is it must be considered to whom the innovation is new. Again in the context of a manufacturing company, the literature has commonly defined 'newness' as 'new to the firm', 'new to the market', or 'new to the user'. High degrees of newness are referred to as 'radical', 'discontinuous' or 'revolutionary'. Low degrees of newness are often termed as 'incremental', 'continuous' or 'evolutionary' (Veryzer, 1998). Hall and Andriani (2002) offer a key differentiator in that the inherently more common incremental innovations are 'additive' in nature, building on existing knowledge and technology, while less common radical innovations are 'substitutive' or 'disruptive', replacing existing knowledge and technology. An example of an incremental innovation is the addition of the Shift key to typewriters, halving the number of keys. An example of a radical innovation is the word processor and its complete substitution of the typewriter. It is noteworthy that authors such as Christensen (1997) have recognised that some radical innovations may not be disruptive, and have therefore discussed incremental and radical separately from 'sustaining' and 'disruptive' innovations. Garcia & Calantone (2002) point out that radical and incremental innovations should not be considered a dichotomy, and instead two ends of a sliding scale.

As with other innovations, eco-innovations can be classified in terms of how radical they are, but the added requirement of reduced environmental impact creates another dimension by which to potentially assess an innovation, measured in eco-efficiency. Eco-efficiency refers to the environmental impact per unit of product or service value (WBCSD, 2000), and is a concept emerging from 'factor' thinking, which looks at the factors by which humans must decrease consumption in order to achieve sustainable development (Brundtland, 1987). To achieve factor increases in eco-efficiency, companies must move from continuous improvement and incremental eco-innovation to more radical forms (Von Weizäcker, Lovins & Lovins, 1997). In other words, to achieve greater reductions in environmental impact, greater changes must occur. This line of thinking brings the scale from low to high eco-efficiency into alignment with the scale from incremental to radical eco-innovation.

The relationship between radical eco-innovation and degrees of eco-efficiency is not necessarily always a perfectly positive correlation. Some incremental eco-innovations may indeed bring about greater improvements in eco-efficiency than some radical eco-innovations, as noted by Ehrenfeld (2001). However, the potential of radical eco-innovation to achieve significant improvements in eco-efficiency is far greater, as radical eco-innovations are not tied to the existing typology. One way to look at the potential for change is to consider that incremental eco-innovations assess the solution to a problem and enhance it, while radical eco-innovations address the problem directly and re-solve it.

Brezet (1997) proposed a model depicting four different levels of eco-innovation; product improvement, product redesign, function innovation and system innovation (Figure 3-1). Each level potentially achieves greater eco-efficiency but takes more time to do so. In level 1 (product improvement) the product is made compliant through pollution prevention and other means, and in level 2 (product redesign) the existing typology is made efficient through the substitution of components for example, perhaps reducing impacts in several lifecycle stages. In level 3 (functional innovation) the desired function is fulfilled in a new way, such as concrete providing passive heating in a house instead of a heater, and in level 4 (system innovation) system-wide changes are brought about by new products and services requiring new infrastructure, such as a Rapid Personal Transit system (RPT - a hybrid between light rail and a taxi service). These levels begin with additive, incremental innovations and end in substitutive, radical innovations. If a line were to be drawn between what this paper defines as incremental and radical, it would split levels 2 and 3. This again indicates a positive correlation between greater eco-efficiency improvements and how radical an innovation must be to achieve them. Empirical research has indicated that most examples of eco-innovations in industry are incremental and only reach stage 2 in Brezet's model (Brezet, 1997; van Hemel & Cramer, 2002).

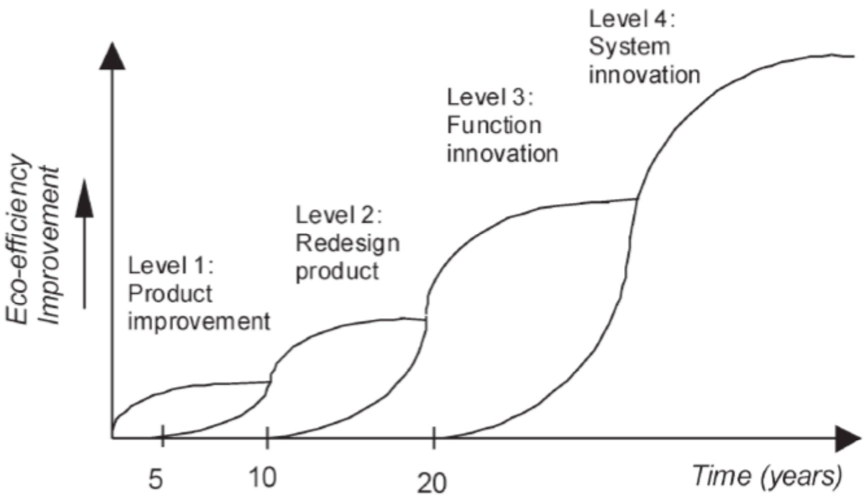

Figure 3-1 Four-Stage Model of Ecodesign

Source: Brezet, 1997

Ehrenfeld (2001) has developed on Brezet's model, attempting to provide further insights in terms of change in device concept, infrastructure, and user learning. These roughly correspond to the aforementioned 'newness to the firm' (device concept), 'newness to the market' (infrastructure) and 'newness to the user' (user learning). The model, depicted as Table 3-1, also redefines Brezet's four levels, providing what the author considers to be clearer divisions between the levels, called 'categories' in this model. Category 1 (process and product redesign) entails any improvement of a product within its current typology, an additive, incremental innovation. An example of this is a more efficient laundry appliance. Category 2 (functional innovation) involves a significant change in device concept to provide the same function as the device it replaces, a substitutive, radical innovation. As with the functional innovation in the model above, the example of concrete passive heating applies. Category 3 (institutional innovation) refers to the replacement of products with services, another substitutive and radical innovation. This is referred to as a Product Service System (PSS) and is explained in the section below. Category 4 (system innovation) is the perhaps the most substitutive and radical, requiring significant changes in the concept, infrastructure and user learning. Again the example of a Rapid Personal Transit system applies. Categories 1 to 4 range from incremental eco-innovation at Category 1, to very radical eco-innovation in Category 4.

Category	Change in Device Concept	Change in Infrastructure	Change in User Learning
1. Process and "Product" Redesign	None to minor	None	None
2. Functional Innovation	Significant	None to Minor	None
3. Institutional Innovation	None to minor	Significant	Significant
4. System Innovation	Significant	Significant	Significant

Table 3-1 Categories of Eco-Innovation

Source: Ehrenfeld (1997)

3.1.2.1 Products or Services

Product Service Systems (PSS) fit into Category 3 and are arrangements where a function traditionally fulfilled by a purchased product is replaced by a service. Instead of selling the product and giving up ownership, the PSS provider retains ownership and is therefore better able to service and reuse the product, potentially resulting in significant improvements in eco-efficiency (Mont, 2002). A well-known example is that of large office copy machines, where clients went from buying a large machine to paying for the service of copying. Due to their high cost and frequent need of servicing, the office copier is considered a prime candidate for a PSS.

3.2 Eco-Innovation as a Process

The innovation process refers to the sequence of events leading to innovation as an outcome. Incorporating eco-innovation into development processes to achieve eco-innovations has been widely attempted to varying degrees across a broad range of industries, and has received even greater attention in the literature, creating a significant lag between theory and practice (Bhamra, 2004). Over the last decade or two there has been a steady proliferation of terms used to describe the incorporation of environmental aspects into product development. This paper uses the term 'Ecodesign', the reasons for this choice and an overview of other terms are provided in Section A in the Appendix.

Much of the ecodesign literature focuses on tools, which help those developing products by analysing environmental impacts (such as Life Cycle Assessments) or assisting to improve designs from an environmental point of view (such as ecodesign handbooks). An overview of ecodesign tools is provided in Section B in the Appendix. Most tools are designed for use after the design specification has been set (McAloone, 2000; Bhamra et al., 1999), in the third design cycle of Figure 3-2 presented below.

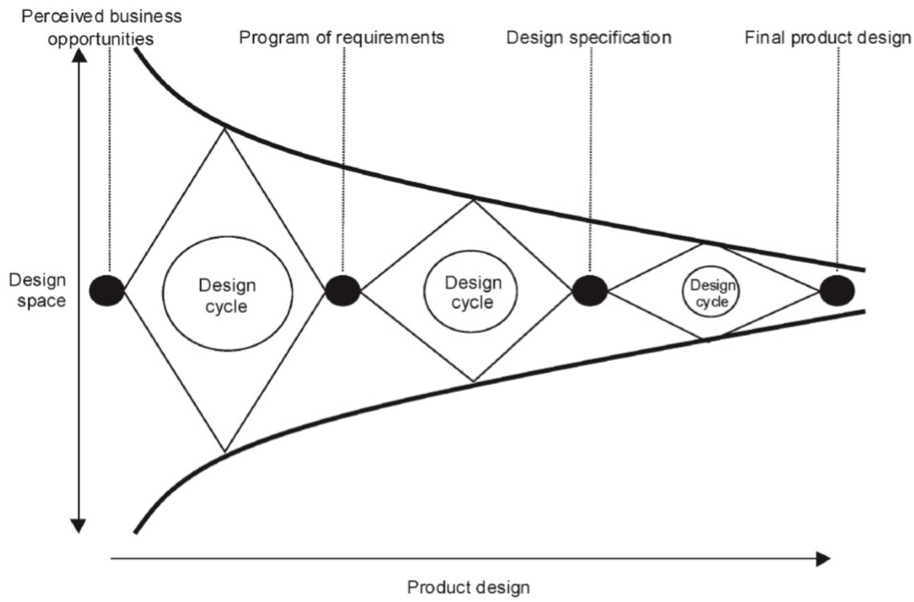

Figure 3-2 Idealized Ecodesign Process

Source: Adapted from Hodgson et al., 1997

3.2.1 Timing

The timing of the environment's integration in the process is considered critical, with early integration offering more potential in bringing about eco-innovation than late integration (McAloone, 2000). This can be seen in Figure 3-2 above, which depicts the decreasing design space (the ability to change the design) afforded as the development progresses. A crucial point in the process is the design specification, where the precise way in which the product will provide its function is set. Attributes such as performance and dimensions do not change after this point. In the later stages in the process, especially after the design specification has been set, the environmental considerations are often at odds with the market demands that were behind the innovation from the beginning, necessitating special ecodesign tools to facilitate their inclusion. When environmental considerations are behind an innovation from its conception there is less of a need to use special tools or methods to integrate them later as environmental and market demands are in line with each other.

3.2.2 Literature Gap

While differences between incremental and radical eco-innovation as an outcome have been well covered in the literature, differences in the processes by which incremental and radical eco-innovations are reached has received less attention. It is reasoned by the author that the apparent dearth in literature in this field is a product of two factors: Firstly that ecodesign literature has typically focussed more on the later stages of the product development process (McAloone, 2000) where incremental innovation is common and information-hungry analysis-based ecodesign tools are most effective. It is at the beginning of the process, amongst greater uncertainty, that radical changes are possible. And secondly that in the early stages there is less of a need for special treatment of environmental considerations as they are likely integrated into the concept and in line with other demands, as explained above. These two factors suggest that in the very early stages it is irrelevant if the innovation is an eco-innovation or a regular innovation as the process would be the same, unlike in later stages where environmental considerations must be treated specially. This could rationalise the apparent lack of literature on radical eco-innovation as a process, as literature from the entirely more established field of New Product Development (NPD) already covers it (see Kleinschmidt & Cooper, 1991; Ali, Kalwani & Kovenock 1993). As such, this section relies mainly on NPD literature in understanding the means by which radical innovations are achieved.

3.3 Variables in the Eco-Innovation Process

Using the terminology of the variables introduced in Section 1.4, the process can be described as beginning with a driver – an event that kicks off the process. In large manufacturing organisations the process is then typically managed through some type of procedure. Different functions in the organisation play important roles in interpreting the drivers and carrying out activities within the procedure. This section looks into existing literature dealing with drivers, procedures, and functions and their roles in incremental and radical eco-innovation. While these three general variables paint a broad picture of why the innovation process begins (drivers), how it is managed (procedures) and who undertakes it (functions), there is a body of literature dealing with more specific factors that are recognised as being important in ecodesign. These success factors (the fourth variable) could exist in all three of the general variables mentioned above, and are examined later in the section.

3.3.1 Drivers

Drivers of eco-innovation are events positively affecting the initiation of the eco-innovation process. These could be the discovery of a need in the market, the introduction of new legislation, or the acquisition of new technological knowledge. Early studies of innovation asserted that the state of available technological development was the primary driver of innovation (see Schumpeter, 1939), a concept widely referred to as 'technology-push'. Later work pointed to the importance of needs identified in the market as the key driver (see Schmookler, 1962; 1966), referred to as 'market-pull', a theory which coincided with the evolution of marketing as a discipline from a selling to a need-satisfying ideology (see Drucker, 1954). Modern literature on the subject is an evolution of the market-pull view and is aligned with marketing theory, but also considers technology a driver (e.g. Rothwell & Zegveld, 1985).

Drivers for eco-innovation are similar to those for other innovations, but with a greater focus on 'regulatory-push/pull' because of the public goods they provide, as mentioned in Section 3.1.1. This is not to say that regular innovations cannot be subject to a regulatory push/pull driver, as this is commonly the case in safety and quality standards for example, which provide non-environmental public goods.

While drivers can be considered as influential *events*, they may be better categorised as the *sources* of those events, such as consumers in creating a need in the market or government in introducing new legislation. These sources come from outside the firm, with the exception of technology in some cases. While much of the time technology does come from external sources (such as suppliers or partners), it will sometimes come from inside the firm through R&D activities. Some literature would term internal sources of technology as a driver, but this paper adopts a strict definition of drivers, as actors *external* to the eco-innovation process who positively influence its initiation. This means the R&D function of the firm is not considered a driver, and instead this paper would consider it to be an important *function* in the innovation process (Another of the dependent variables, see Section 3.3.3).

Drivers are inherently difficult to categorise, as one driver may be entirely or partly driven by another. Consumers may exhibit increased demand for environmentally friendly products, perhaps as a result of information recently made accessible by legislation, and perhaps because of a recent campaign highlighting environmental issues by an NGO. Identifying the driver or drivers in such a case is a highly subjective, but necessary task in analysing and communicating a complex interaction such as the forces behind the initiation of an eco-innovation. The strict definition used here narrows the scope of potential drivers to external influences, allowing internal factors to be covered by the three other dependent variables (procedures, functions and success factors).

The literature mentions other drivers, such a management vision, or a sense of company responsibility to 'do the right thing' (Bhamra, 2004). These do not conform with the definition for drivers used in this paper, as there are likely external drivers behind these drivers, such as the increased interest from potential investors and employees should a company be 'doing the right thing'. This paper would consider the external actors as drivers in such a case, and might consider the attention from management to environmental issues in response to that driver as a 'success factor' (another dependent variable, see Section 3.3.4). Another commonly cited driver of eco-innovation is the entrepreneurial spirit of the designer or engineer, not influenced by external factors so much as by an internal existential need to create and innovate. Due to this paper's definition of drivers as being outside the innovation process, this would not be considered a driver but instead a 'success factor' (an 'environmental champion', see Section 3.3.4)

3.3.1.1 Drivers for Incremental and Radical Eco-Innovations

Demands from the market are a crucial driver in all product development, but it is reasoned in the literature that as consumer preferences do not change radically, articulated consumer needs are far more likely to lead to incremental and not radical innovations (Foster & Green, 2000). NPD literature notes the unspecific market opportunities that come with radical innovations (O'Connor, 1998; Rice, O'Connor, Peters & Morone, 1998), and even asserts that market information may be of no assistance in the development of radical innovations (Balachandra & Friar, 1997; Veryzer, 1998). Christensen (1997) goes so far to say that listening too carefully to the market may lead companies astray from opportunities in radical innovation. Veryzer (1998b) points out that even verifying concepts with the customer can pose problems for radical innovations, as consumers' unfamiliarity with radical concepts leads to unpredictable and inconsistent product evaluations. This is due to consumers being entrenched in the status quo, making it hard for radical innovations to dislodge established products. This can mean that the main competitor for a firm introducing a radical innovation is not another firm, but the current way of doing things (Veryzer, 2005).

However, complete disregard of market information is not suggested by the literature, as empirical research has often encountered cases where what R&D thought would suit consumers well eventually failed when introduced to the market (Veryzer, 1998). This suggests a need for market information in the process without control by it. In the absence of the market as a driver, NPD literature tends to assert the importance of technology in radical innovation, where partners such as universities are suggested as potential sources of new knowledge (Foster & Green, 2000).

3.3.2 Procedures

The creative process has been likened to watching a video of an explosion played in reverse, with all manners of debris floating about in seeming disarray before suddenly forming into a solid object (Lloyd & Deasley, 1998). The procedures by which large manufacturing organisations structure this process are commonly referred to as 'product development processes'. To avoid confusion with the overarching discussion of eco-innovation as a process, this study refers to product development processes as 'procedures'. Various generic models of these procedures exist in the literature (e.g. Pugh, 1999; Rothwell & Zegveld, 1985). The International Standards Organisation (ISO, 2002) provides the following basic model.

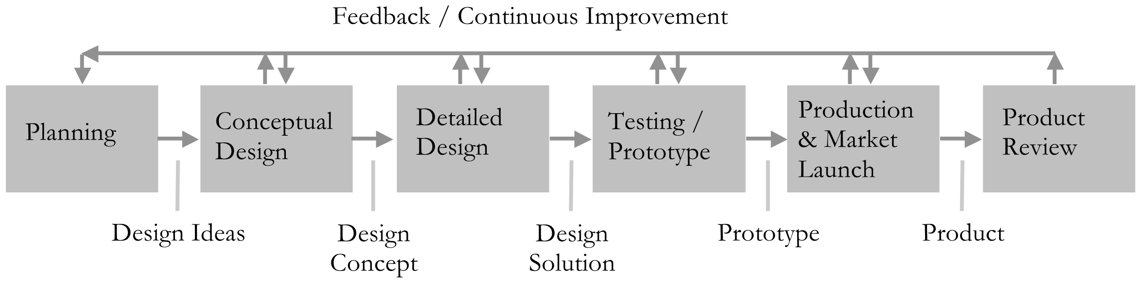

Figure 3-3 Generic Product Development Procedure

Source: ISO, 2002

Procedures typically employ 'stage-gate' systems, dividing sequential activities with gates or checkpoints where criteria must be met and decisions made before passing on to the next stage. These checkpoints assist teams in working towards common targets and can be used to include environmental criteria in the process (Griffin & Hauser, 1996).

3.3.2.1 Procedures in Incremental and Radical Eco-Innovation

While some innovation processes lend themselves to being managed by a linear procedure, others do not. The literature differentiates between rational linear sequences and non-rational unstructured collections (Schon, 1967).

The rational approach is similar to that depicted in Figure 3-3 and perceives the innovation process as a sequential series of activities with feedback loops, starting from the identification of need and moving through research, design, testing, production and commercialisation (e.g. Kline & Rosenberg, 1986). This is how most manufacturing firms manage innovation.

The non-rational approach is not so much managed but evaluated, involving unexpected twists and turns (Schon, 1967). This approach may not follow any predetermined structure and therefore does not lend itself to being modelled in a procedure. Schon (1967) argues that radical innovations entail less rational and less predictable development processes.

NPD literature asserts that the differences between incremental and radical innovation processes are so great that a procedure suitable for incremental innovation would be unsuitable and possibly detrimental if applied to radical innovation processes (Lynn, Morone & Paulson, 1996; Rice et al., 1998). It has been suggested that the major differences between radical and incremental innovations reside at the very beginning of the process where drivers are interpreted (Veryzer, 1998). This stage is known as the Fuzzy

Front End (see Reid & Brentani, 2002). At this early stage, activities commonly undertaken in incremental innovation processes (such as market verification) may not be possible in radical innovations and may even prove to be counter-productive (Veryzer, 1998; 2005). Empirical research indicates that while linear stage-gate procedures are suitable for the management of incremental innovations, they are not conducive to more radical innovations, which, as mentioned above, tend to be better evaluated than managed (Veryser, 1998). The same study found characteristics of radical innovations to include a more explorative and less consumer-driven approach.

In summary, the literature associates incremental innovation with more linear and rational processes, which adhere to procedures used to manage them. Radical innovation is not considered to adhere to predefined procedures, as it has unpredictable and non-rational processes.

3.3.3 Functions

Functions in this paper refer to groups of people in the company carrying out a similar activity (such as sales). As mentioned in Section 3.2.1, the early integration of the environment is important in achieving radical eco-innovation, so this section is concerned with those functions involved early in the process. According to NPD literature, key functions in the early stages of the typical innovation process in a manufacturing firm are Marketing, Research and Development (R&D) and Industrial Design (Veryzer, 2005). Marketing developed in the late 1950s from a post-production activity to an integral function in the development of products (Drucker, 1954) and is responsible for identifying opportunities on the market and understanding the consumer. Marketing gathers information through market research and communicates it to relevant functions to ensure products are designed to best satisfy the identified needs of the consumer. Industrial Design has grown in importance in the last 15 years and deals with user–product interfaces, ergonomics and aesthetics (Perks et al., 2005). Research and Development (R&D) has attracted increasing resources in recent decades and is generally concerned with the investigation of new technologies, reducing the associated risk to allow their use in Product Development.

Typically less important functions at this stage are Product Development, Manufacturing, Sales and Environmental Management. Product Development generally works after the product specification has been set, determining the mechanical design of products (Veryzer, 2005). Environmental Management is often integrated later in the process, providing environmental expertise and taking responsibility for compliance to regulation.

Functions carry out their central activities at different stages of the procedure used to manage product development. While Marketing may work across all six stages in figure 3-3, Manufacturing may operate only in the fifth. With the use of cross-functional teams and improved communication within organisations, a more concurrent integration of functions is possible, as depicted in Figure 3-4. It should be noted that Figure 3-4 indicates the possible inclusion of various functions in meetings, not that Manufacturing conducts activities in the 'planning' or 'conceptual design' stages in Figure 3-3 above. As depicted in Figure 3-4, Marketing is typically the initial function involved in the process, conducting market research and applying its understanding of the market to the concept generation stage.

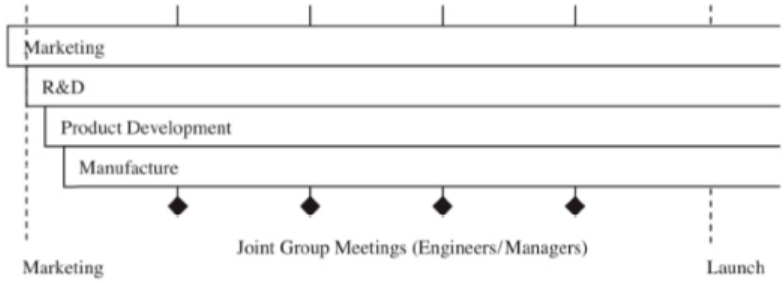

Figure 3-4 Functional Integration in Innovation

Source: Adapted from Rothwell, 1994

3.3.3.1 Functions in Incremental and Radical Eco-Innovation

Marketing is typically involved from the beginning of the process, but perhaps less so in radical innovation. As discussed in Section 3.3.1.1, market information is not considered as important for radical innovation as it is for incremental innovation. Instead R&D is deemed to play a more important role in directing radical innovation (Leonard-Barton & Wilson, 1994). Based on findings of empirical studies of Fortune 500 companies, Veryzer (2005) asserts that radical innovations usually originate in and are driven by the R&D function. Radical innovations are often developed under conditions of high technical and market uncertainty, which do not suit the typical input of the marketing function until a later stage. The study found that consumer research for radical innovations was not conducted until after prototypes had been constructed, showing a late integration of the Marketing function (Veryzer, 2005). Although radical innovations appear to be more R&D-centric, the input of Marketing is essential to avoid the potentially disastrous consequences of R&D developing blindly (Veryzer, 2005).

3.3.4 Success Factors

A number of authors have attempted to determine success factors in integrating environmental aspects into product development. These ecodesign success factors are a broad variable that could overlap any of the three previous variables of: Drivers, procedures or functions.

This limited literature review has identified and categorised 13 such success factors. The criteria for inclusion being that each factor should be identified in more than one of the 11 studies that were looked into (for a full review of literature on ecodesign success factors see Johansson (2002)). The factors are listed in Table 3-2 below in order of prevalence in the literature studied, from most to least common.

Success Factor	Literature
Commitment to ecodesign from top management	ISO, 2002; Ehrenfeld & Lenox, 1997; Pujari et al., 2003; McAloone, 2000; Ritzén & Beskow, 2001; McAloone, 1998; Johansson, 2002
Ecodesign training provided to product development personnel	ISO, 2002; Foster & Green, 2000; Ritzén & Beskow, 2001; Johansson 2002
Existence of an environmental champion close to the process	McAloone, 2000; Pujari and Wright, 1996; McAloone & Evans, 1997; Johansson, 2002
Access to environmental specialists for product development personnel	Ritzén & Beskow, 2001; Ehrenfeld & Lenox, 1997; Johansson, 2002
Cross-functional teams used in product development	ISO, 2002; McAloone, 2000; Johansson, 2002
Mindset prioritising environmental issues as business issues	McAloone, 1998; McAloone & Evans, 1997; Johansson, 2002
Use of appropriate ecodesign tools	Ritzén & Beskow, 2001; McAloone & Evans, 1997; Johansson, 2002
Consumer needs-focussed ecodesign	Pujari & Wright, 1996; Johansson, 2002
Close supplier relationships	Pujari et al., 2003; Johansson, 2002
Environmental requirements integrated in the product development procedure	Ritzén & Beskow, 2001; Johansson, 2002
Participation encouraged in ecodesign activities	Ritzén & Beskow, 2001; Johansson, 2002
Good communication of environmental information within the company	ISO, 2002; McAloone & Evans, 1997
Early integration of environmental considerations	McAloone, 1998; McAloone & Evans, 1997

Table 3-2 Success Factors in the Literature

3.3.4.1 Success Factors in Incremental and Radical Eco-Innovation

Unlike the sections above on drivers, procedures and functions, which could draw on existing NPD literature to differentiate between incremental and radical innovation, this section involves specific success factors identified through empirical research without reference to incremental and radical types of eco-innovation. The analysis section (7) aims to ascertain which factors apply to incremental and radical eco-innovations.

3.3.5 Interrelation between Drivers, Procedures and Functions

It is important to note the high degree of interrelation between the four variables presented above. Greater involvement of Environmental Management functions early in the innovation process would naturally lead to greater access to environmental specialists, a success factor. If consumers are an important driver, the Marketing function is inevitably involved from the beginning of the process. If the typical procedure begins with an analysis of the market, the Marketing function will be involved from an early stage if the procedure is followed.

3.4 Summary of the Literature

The literature review defined innovation and eco-innovation as an outcome, and explained the differences between incremental and radical eco-innovation. While incremental eco-innovation is more common, radical eco-innovation provides greater potential for improvements in eco-efficiency. The review then examined eco-innovation as a process, with a focus on four aspects: Drivers initiating the innovation process, procedures used to manage the process, functions involved early in the process and success factors in ecodesign. The table below presents the main differences found in the literature between incremental and radical eco-innovation for the first three variables. No differences were found for the fourth variable – success factors – as there is no literature suggesting how it might differ between incremental and radical eco-innovation.

	Drivers	Procedures	Functions	Success Factors
Incremental	Market	Typical	Marketing	n/a
Radical	Technology	Atypical	R&D	n/a

Table 3-3 Summary of the Literature

It is important to note that only two categories of innovations are presented here (incremental and radical), when Ehrenfeld's table in Section 3.1.2 outlines four different categories of eco-innovation – one incremental and three different radical categories. The NPD field, which is the origin of the literature used in this review to identify potential differences between incremental and radical innovation, does not differentiate between levels of radical innovation in the same way as the eco-innovation field does, bundling all levels into the term 'radical'. The clearer categorisation of radical eco-innovation over radical innovation is perhaps due to the special attention given to categories such as institutional eco-innovation in studies of Product Service Systems. The NPD field's discussion of radical innovation does not pay much attention to the shift from product to service provision, and instead focuses on innovations involving significant change in the device concept (while institutional innovations have none to minor changes in the device concept). Therefore it is reasoned that the findings from the literature will have full applicability to Ehrenfeld's functional eco-innovation, but perhaps less applicability to institutional and system innovation.

4 Analytical Framework

This section introduces a framework with which to analyse the data, meet the research objectives and thereby answer the research question. The research question and objectives established in Section 1.4 are revisited in the diagram below.

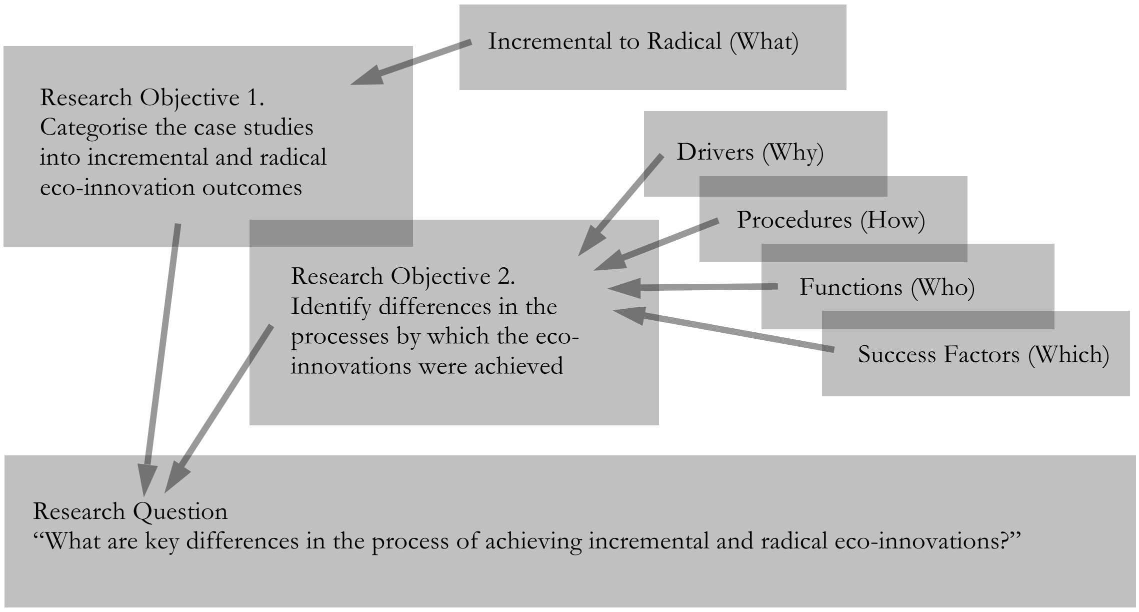

Figure 4-1 Research Outline

4.1 Meeting the Research Objectives

The analysis discusses the two research objectives, and then synthesises the results to answer the research question.

4.1.1 Objective 1: Categorising Cases as Eco-Innovation Outcomes

4.1.1.1 Outcome

Using the categories proposed by Ehrenfeld, the five case products are categorised in terms of how incremental or radical they are as an eco-innovation outcome. Category 1 is incremental, while categories 2, 3 and 4 are increasingly radical. The following table is based on that of Ehrenfeld but has an additional column where the cases are categorised.

Category	Case	Change in Device Concept	Change in Infrastructure	Change in User Learning
1. Process and "Product" Redesign		None to minor	None	None
2. Functional Innovation		Significant	None to Minor	None
3. Institutional Innovation		None to minor	Significant	Significant
4. System Innovation		Significant	Significant	Significant

Table 4-1 Analytical Framework: Eco-Innovation Outcomes

4.1.2 Objective 2: Differences in Eco-Innovation as a Process

By looking at drivers, procedures, functions and success factors, Objective 2 identifies differences in the processes by which the eco-innovations were achieved.

4.1.2.1 Drivers

For each case, the drivers involved are categorised in terms of how instrumental they were in spurring the innovation process. The categorisations consist of Significant, Minor and None. These categorisations are based on the frequency with which respondents mention certain drivers and the importance they convey about each driver.

4.1.2.2 Procedures

Procedures for each case are categorised by how much they deviate from the typical procedure. The typical procedure is established in the Base Case with a description of the procedure employed by Electrolux. Due to limitations in the data collection, subtle deviations from the procedure were not possible to confirm and only dramatic deviations were recorded. In an attempt to better categorise this variable, a second line of analysis has been added concerning the flow of environmental information amongst functions and between functions and drivers. Environmental information is loosely defined as information communicated from one driver or function to another that positively influences the development of an eco-innovation. An example could be the environmental management function getting wind of new legislation (one flow) and communicating that information to another function such as R&D (another flow of environmental information). Again the cases are compared to the typical situation – essentially all potential flows of environmental information identified in the Base Case. The divergence from the procedure is determined by the extent to which environmental information does not travel along the typical paths identified in the Base Case. These two lines are assessed equally to determine the extent to which a case deviates from the typical procedure. This variable is also categorised as: Significant, Minor or None.

4.1.2.3 Functions

Functions are categorised in terms of the extent to which they were involved at the very beginning of the innovation process. As above, the categorisations comprise of Significant, Minor and None. And as with the drivers variable, these categorisations are based on the frequency with which respondents mention certain functions and the importance they convey about them.

4.1.2.4 Success Factors

A selection of six success factors has been chosen from the 13 identified in the literature review. The success factors selected were determined to be both relevant to the Product Cases and are also some of the more commonly identified success factors in the ecodesign literature reviewed. Those factors not selected presented issues in data collection or applicability. Unlike the previous three variables, which look for differences between incremental and radical innovations in order to eventually identify leverage points, this variable takes recognised leverage points and investigates their applicability to incremental and radical eco-innovations. The presence of each factor is categorised as Significant, Minor or None. To provide context, the Base Case is also assessed. The six factors are presented below.

- Commitment from top management to eco-innovation
- Ecodesign training provided to product development personnel
- Existence of an environmental champion close to the process
- Access to environmental specialists
- Cross-functional teams used in the process
- A mindset prioritising environmental issues as business issues

An important consideration when discussing success factors in relation to individual cases is the matter of time. The first and last factors in the list above are not only difficult to measure, but could be relatively long term when compared to the length of a case (the development of a product) which might last only one or two years. That these factors are unlikely to change year by year could present issues in determining if indeed the company did have either of these success factors at the specific time of an individual case. The literature reviewed in this study did not generally test success factors against individual product cases and therefore did not cover the issue of time in detail.

Similar issues arise with the second factor, training, as it is problematic to determine when training has an effect on the development process. Considering employee turnover and their forgetting of trained skills, if a case occurred 5 or 10 years after a one-off one-year training programme, would the employees be 'trained'? This study arbitrarily assumes that the effect of training is halved after 5 years and lost after 10 years. This means that Product Cases within 5 years of the end of a training programme will have significant training, those between 5 and 10 years after will have minor training, and those 10 years or more after will have none. While there are significant limitations to such an assumption, it is necessary to assess the success factor training in relation to individual cases.

4.2 Synthesising the Objectives

This section combines the results of the objectives, comparing the differences in Drivers, Procedures, Functions and Success Factors with how incremental or radical the product case innovation outcome is.

4.2.1 Drivers

The drivers for each case are plotted against how incremental or radical the eco-innovation outcome is. To depict this Ehrenfeld's table has been modified, replacing the x-axis with the various potential drivers. A score of Significant, Minor or None will be given to each combination of Product Case and driver.

Category	Case	Consumers	Customers	Retailers	Competitors	Partners	Suppliers	Investors	Employees	Government	NGOs
1. Process and "Product" Redesign											
2. Functional Innovation											
3. Institutional Innovation											
4. System Innovation											

Table 4-2 Analytical Framework: Drivers

The 10 drivers were identified using Electrolux's own list of stakeholders and modifying it to include only those drivers likely to communicate environmental information (not labour unions for example). To facilitate comparison with the literature, the drivers are condensed into three broad categories: Market (those exerting influence after Electrolux in the supply chain: Consumers, Customers, Retailers and Competitors), Industry (those exerting influence beside or before Electrolux in the supply chain: Partners, Suppliers, Investors and Employees) and Governance (those exerting influence from outside the supply chain: Government and NGOs). The simplified categories are plotted in Table 4-3 below. The data is the same as that used in Table 4-2 above, and is averaged and rounded when two conflicting scores appear in the same grouping.

Category	Case	Market	Industry	Governance
1. Process and "Product" Redesign				
2. Functional Innovation				
3. Institutional Innovation				
4. System Innovation				

Table 4-3 Analytical Framework: Driver Groupings

4.2.2 Procedures

The degree to which the observed procedure deviates from the typical procedure is plotted against how radical or incremental the innovation outcome is in the following table.

Category	Case	Change in Procedure
1. Process and "Product" Redesign		
2. Functional Innovation		
3. Institutional Innovation		
4. System Innovation		

Table 4-4 Analytical Framework: Procedures

4.2.3 Functions

The functions involved at the beginning of the process are compared in the following table.

Category	Case	Product Line Mgmt & Marketing	Consumer Innovation Programme	Product Development	Primary Development	Core Technology & Innovation	Group Sustainability Affairs	Environmental & European Affairs	Industrial Design	Group Management	Manufacturing	Sales
1. Process and "Product" Redesign												
2. Functional Innovation												
3. Institutional Innovation												
4. System Innovation												

Table 4-5 Analytical Framework: Functions

As with the drivers variable, the functions are condensed to allow comparison with the literature. The 11 main Electrolux functions are categorised into four basic groupings based on the literature review in Section 3.3.3 and interviews for the Base Case. The groupings are: Marketing, R&D, Environmental Management and Other. The first three groupings contain functions with similar roles, such as R&D with Product Development, Primary

Development and Core Technology and Innovation (explained in Section 5.6). The fourth grouping consists of a mix of other important functions that do not fit within the first three groupings. As in the drivers variable the table below is used to reassess the data from the table above.

Category	Case	Marketing	R&D	Environmental Management	Other
1. Process and "Product" Redesign					
2. Functional Innovation					
3. Institutional Innovation					
4. System Innovation					

Table 4-6 Analytical Framework: Function Groupings

4.2.4 Success Factors

The presence of the six success factors in each case is plotted in the following table. An additional row is added so that the Base Case can be included in the analysis for context.

Category	Case	Top Mgmt Commitment	Ecodesign Training	Environmental Champions	Access to Specialists	Cross-functional Teams	Environmental Mindset
1. Process and "Product" Redesign							
2. Functional Innovation							
3. Institutional Innovation							
4. System Innovation							
	Base Case						

Table 4-7 Analytical Framework: Success Factors

5 Base Case: Electrolux

The Base Case explains the Electrolux organisation, its products and its experience with ecodesign before covering the four variables of analysis: Drivers, procedures, functions and success factors.

5.1 The Organisation

Electrolux Group is a Swedish manufacturer of consumer and professional appliances, selling to 150 countries and employing 57 000 people (Electrolux, 2008b). Founded in 1912, the company experienced rapid growth from the 1970s onward, which can be attributed to its acquisitions of brands such as Husqvarna, Zanussi, Frigidaire and AEG (Personal Communication (hereafter PC), 2008g). Until 2006 Electrolux was the world's largest manufacturer of major appliances but is now second to Whirlpool Corporation of the United States (PC, 2008g). The company produced 40 million products in 2007, which were split between its four main product divisions; Fabric Care (washing and drying, 20% of sales), Kitchen (refrigeration, cooking and dishwashing, 58%), Floor Care and Small Appliances (8%), Other Sales (7%) and Professional (7%) (Electrolux, 2008a). Under its various brands Electrolux had global sales of 105 billion SEK in 2007, of which 45 billion were in Europe where Electrolux remains the largest manufacturer and employs 26 000 people (Electrolux, 2008b).

5.1.1 Organisational Structure

Electrolux has its global headquarters in Stockholm where many of its Group-level corporate functions are located. Operational functions are divided geographically for consumer durables between Europe (42% of sales), North America (31%), South America (9%), Asia Pacific and the Rest of the World (9%). Global professional products make up the remaining 7% of sales (Electrolux, 2008a). The company has a decentralised organisational structure due to the strong geographic divisions that result from both the company's history of acquisition and the diversity in consumer preferences between countries (PC, 2008c). Functions within Electrolux Major Appliances Europe may operate across all consumer durable product divisions, for a specific division (such as Fabric Care) or for a specific product line (such as dryers). This paper will categorise Electrolux functions into Group, Europe, Product division and Product line levels. The different functions and their levels within the organisation are explained in more detail in Section 5.6.

5.2 The Product

While virtually all households in developed European countries have a washing machine or access to one (ISIS, 2007a), the penetration of dryers – although growing – is much lower and varies greatly between countries (PWC, 2008a; 2008b). The industry for laundry appliances is slow-moving due to a low replacement rate, and has low margins compared to the automobile and consumer electronics industries because of stiff competition (PC, 2008l). Front-loading horizontal-axis washing machines have long been the dominant typology in Europe, compared to the top-loading vertical-axis configuration traditionally favoured in North America. The horizontal-axis utilises gravity to mechanically agitate the clothing instead of electrical energy as in the vertical-axis, resulting in greater energy and water efficiency, washing performance, and less wear on clothing. However the horizontal-axis takes more time to complete a cycle and generally costs more to produce (PC, 2008h).

5.2.1 Plateauing Efficiencies

The industry's attention to the energy consumption of its products has resulted in substantial improvements in energy and water efficiency. As mentioned in Section 1, today's washing machines use 60% less energy and 65% less water per kg of washing than the machines of 20 years ago (Electrolux, 2007a). However in recent years the marginal improvements in efficiency have decreased and the average efficiency over product ranges is beginning to plateau. Refer to Figure 12-1 in the Appendix for annual efficiency gains for washing machines. It is the general opinion of interviewees that washing machines will soon hit a ceiling in energy efficiency in their current typology and for further major improvements in efficiency to occur there must be a radical change (PC, 2008c; 2008i; 2008l). Dryers have seen a similar plateau in efficiency in their common typology, which is not expected to become much more efficient (PWC, 2008a). However the recent introduction of heat pump technology to the dryer has led to dramatic improvements in efficiency and has begun a new efficiency curve (PWC, 2008a) (this product is covered as a case in Section 6.2). Refer to Figure 12-2 in the Appendix for a visual representation of the heat pump dryer's efficiency curve, which demonstrates how the heat pump typology will also plateau soon. Heat pump technology is not suited for use in a washing machine and no such innovation is foreseen (PC, 2008i).

5.2.2 Possible Directions for Future Radical Eco-Innovation

The development of major appliances with less impact on the environment is a well-discussed topic in certain media, demonstrated by the considerable interest in Whirlpool's Green Kitchen concept. Most discussions focus on three areas.

5.2.2.1 Appliances

While the efficiency improvements in the current typology are limited, radically different concepts of a washing machine may present greater efficiencies. Many concepts look to use waterless washing and/or different cleaning agents, with notable examples being the use of soap nuts or plastic chips instead of chemical detergents. Another potential cleaning agent is steam, which is in fact covered in one of the Product Cases in Section 6.4.

5.2.2.2 Behaviour

Appliances are likely to soon have better feedback for the user, providing information on the consumption of energy and water for each cycle selected and allowing users to better understand the appliance and use it more efficiently. With the assistance of smart meters replacing traditional electricity and water meters in homes, more detailed information could be provided on the cost of the electricity used. Smart meters have the ability to record electricity consumption accurately and communicate readings with a central hub. They can also retrieve information from the electricity grid as to the current demand and price of electricity. Simply understanding the resources used can make users more efficient whether they are a 'green consumer' or not. It has been likened to golf, which wouldn't be nearly as interesting if one didn't get a score at the end (Derrel, 2008).

5.2.2.3 Systems

Innovations extending beyond single appliances and single washing and drying cycles allow greater potential for energy efficiency. Washing machines and dryers waste considerable energy both as vibrations and as heat discharged in water and air. The water disposed after the final rinse is cleaner than is required for the first rinse of the next cycle, but new water is used each time. Dishwashers waste water and heat in a similar way to washing machines and refrigerators constantly produce waste heat. The potential for recovery and reuse of energy and water amongst household appliances is estimated by Whirlpool's Green Kitchen concept to be 40% (Derrel, 2008).

The following theoretical example illustrates how the three areas of potential innovation could be combined to achieve significant energy efficiency improvements. The user would fill the washing machine, which would weigh the clothing and indicate to the user how much more could fit inside, discouraging sub-capacity loads. The user would then select the type of clothing and by when they would like it washed. The detergent would have already been loaded in bulk to be dispensed accurately by the machine, avoiding over-dosing. The machine would refer to other appliances in the home for potential sources of thermal energy and reusable water, perhaps to a solar heater on the roof or other local sources of hot water, and to the electricity grid to determine the current and predicted demand and price of electricity. Using this information the machine would calculate the cheapest and most efficient combination of energy and water sources, energy types (kinetic, thermal and chemical – explained in Section 6.1.1), and time before advising the user of the cost and even estimated environmental impact of the calculated washing options (PC, 2008l).

5.3 The Environment

The following text explains Electrolux's strategy in relation to environmental issues, the company's most significant environmental aspects and how they manage these aspects.

5.3.1 Proactive Strategy

In 1994 Greenpeace Sweden dumped 50 of Electrolux's own refrigerators in front of the gates at Electrolux headquarters to protest the company's choice of refrigerant (Maté, 2001). This is recognised by both interviewees (PC, 2008n; 2008g) and in the company's Annual Report (Electrolux, 2002b) as being a turning point from a reactive to a proactive approach toward environmental issues. Electrolux began working with the Natural Step in 1994 and addressed various environmental issues during the 1990s, becoming recognised as an environmental leader in its industry (Electrolux, 2002b).

Today Electrolux considers its environmental performance a competitive advantage (Electrolux, 2008b), and from 2008 has begun to promote its 'Green Range' of products in a major marketing campaign. While Electrolux works to reduce the impact of all of its products, the Green Range refers to a group of products with the best environmental performance among Electrolux offerings. An evolving set of criteria is used to select products for the Green Range, a selection now accounting for nearly a quarter of gross profit in Europe (Electrolux, 2008b). Interviewees were of the opinion that although Electrolux had been working with these issues for 15 years now, it has been in the last few years that factors such as energy prices and water scarcities have become stronger, as has Electrolux's proactivity towards environmental issues. The Green Range had existed as a concept within the company for years but only after a Group level decision in 2007 to promote environmental products more was the marketing campaign initiated (PC, 2008g).

5.3.2 Managing Environmental Aspects

5.3.2.1 Environmental Policy

Electrolux's environmental policy was first published in 1993 and last updated in 2001. It stipulates that with regard to its products the company is committed to *"Designing products to reduce their adverse environmental impact in production, use and disposal"* (Electrolux, 2005a). It is communicated to all employees and its implementation is the responsibility of the product lines.

5.3.2.2 Life Cycle Assessments

Life Cycle Assessments (LCA) are used to determine environmental impacts over a product's entire lifecycle and are covered in more detail in Section B in the Appendix. LCAs have been conducted on Electrolux products by research institutes, universities, consultants and Electrolux since 1994. No extensive LCAs have been undertaken in the last few years (PC, 2008g; 2008v).

The LCAs have indicated that the vast majority of a washing machine's impact is associated with energy consumption during use. One study attributed 72% of impacts to energy and 4% to water consumption during the use phase. The next greatest impact came from the materials used to construct the washing machine (22%), with only 2% coming from manufacturing and 0.2% from transport (Rüdenauer et al., 2004). Dryers have similar distributions of impact with the exception of water in the use phase. Refer to Figure 12-3 in the Appendix for a visual representation of the cited LCA results.

5.3.2.3 Use Impacts

Energy consumption during use is tackled by continuous improvements in energy efficiency in Electrolux's products. Water efficiency is inherently related to energy efficiency, and can be targeted alongside it (PC, 2008i). Noise pollution during use has been reduced significantly in the last 20 years, driven by the increasing proximity of laundry equipment to living spaces in modern urban housing (PC, 2008n).

5.3.2.4 Material Impacts

Materials in a washing machine must be able to withstand hot and wet conditions over a long period. Steel is commonly used throughout the machine, with concrete utilised to provide weight and stabilise the spinning action. Electronics are common in laundry appliances requiring a variety of materials, and in addition to more benign plastics PVC is used where specific technical requirements necessitate it. Electrolux has removed PVC from products when demanded by certain markets, such as Sweden and Germany (PC, 2008g; 2008h). Interviewees explained that while Electrolux would like to eliminate PVC from all markets, margins in the industry are too low to take on the cost without the assistance of legislation in banning it across the industry (PC, 2008f).

Impacts embodied in materials are controlled through a Restricted Material List (RML) and recycling of the product after disposal. Electrolux has used an RML since 2004, it is maintained at the group level and certain details are adapted to each region (PC, 2008g). In Europe, the Environmental and European Affairs function (covered in Section 5.6.3.2) is in charge of implementing the RML and putting in place operational measures to phase out materials identified in the list (PC, 2008v). Electrolux and other manufacturers contract out the recycling of old appliances. Despite usually having many working parts in good condition, recovered washing machines and dryers are shredded and sorted automatically for recycling. Interviewees provided reasons as to why refurbishment or reuse of products or parts is not undertaken; A large number and variety of low-value machines exist untracked in the marketplace, individual components in machines are not of high economic value and not worth manually recovering, and the 14 year average life of the machine often means that the design has changed significantly before products are returned from the market (PC, 2008v).

5.3.2.5 Manufacturing Impacts

Although manufacturing has a very small share of the product's total impact, Electrolux's 53 production facilities account for 95% of the company's *direct* impact on the environment (Electrolux, 2008b). Factory operations primarily involve the assembly of components from suppliers, but also metalworking, plastic moulding, painting, enamelling and metal casting, resulting in environmental aspects in energy and water consumption, emissions to air and water, and solid waste generation (Electrolux, 2005b). The material balance in 2006 saw close to 92% of input materials leave factories as products and packaging, reflecting the dominance of assembly operations (Electrolux, 2007b). Electrolux strives for continuous improvement under its Environmental Management System (EMS) and mandates that all facilities with 50 or more employees must be ISO14001 certified within 3 years of acquisition (Electrolux, 2008b). In 2007 over 90% of such facilities were certified worldwide (Electrolux, 2008b). Electrolux aims to reach a company-wide aggregate target of a 15% reduction in energy use in manufacturing over value added by 2009 (PC, 2008k; Electrolux, 2008b). The EMS covers only manufacturing facilities and does not extend to other functions such a product development.

5.3.2.6 Ecodesign Tools

In addition to LCAs and its RML, Electrolux incorporates environmental requirements in its stage-gate process, as described in Section 5.5. Quality Function Deployment (QFD) and Failure Mode Effect Analysis (FMEA) are NPD tools explained in Section C in the Appendix, and are used in the Primary Development (PC, 2008i) and Product Development stage (PC, 2008f; 2008j) of Electrolux's procedure (see Section 5.5). QFD was said to be used mainly by R&D and not by Marketing functions (PC, 2008t; 2008n). One respondent mentioned that environmental aspects were integrated into tools such as QFD through input from cross-functional teams (PC, 2008i), but the use of a formal methodology for environmental QFD was not mentioned. Ecodesign handbooks were developed in the late 1990s and were distributed throughout the organisation. However, according to interviewees their use eventually ceased and the handbooks are no longer readily available (PC, 2008v). The interviews did not reveal the use of any of the other tools identified in Section B in the Appendix.

5.4 Drivers

This section describes the various drivers of eco-innovation at Electrolux. The drivers are explained according to their grouping, as presented in Section 4.2.1. This section also covers the type of environmental information being communicated, which is in fact part of the procedure variable in the analysis, but is best explained alongside drivers.

5.4.1 Market

This section explains those drivers after Electrolux in the supply chain: Consumers, Customers, Retailers and Competitors.

5.4.1.1 Consumers

Consumers communicate environmental information to Electrolux either through direct contact or through their purchasing of products with high environmental performance. Respondents mentioned that questions from consumers regarding products and processes were common (PC, 2008g). However the communication of environmental preferences through purchasing decisions is an economic driver and is therefore likely to have more influence on the company.

In 2007 Electrolux conducted a survey of 2 400 consumers in 12 European countries, which identified high and increasing environmental awareness (Electrolux, 2007c). 70% of respondents were concerned or extremely concerned about the environment, while 68% of people considered themselves more environmentally aware than a few years ago. 70% wanted their appliances to be environmentally friendly, which was the second strongest need behind being 'easy to use', desired by 77% of respondents. 76% of people in the survey said they compare energy labels when purchasing appliances, and in a background study for the EU EuP directive 'low water and/or energy consumption' ranked highest among considerations when purchasing new major appliances (ISIS, 2007b). When asked to rank environmental aspects in terms of consumer awareness, interviewees from Electrolux for this study put energy consumption during use in first place, followed by noise and then water consumption (PC, 2008e; 2008g). However the extent to which consumers' in-store behaviour lives up to survey answers is of course debatable.

The purchasing behaviour of consumers does point toward greater awareness, which is reflected in the opinion of interviewees (PC, 2008f; 2008l; 2008e; Electrolux, 2008b). Electrolux has experienced commercial success with products with an environmental profile, but whether consumers chose those products for environmental reasons is not clear. A washing machine with high centrifuge speeds of 1600 or 1800rpm will dry clothing quicker and reduce the need for a dryer or the time in a dryer if one is used, reducing environmental impact, cost to the consumer, and time used. However, which of these benefits the consumer purchases for cannot be easily determined (PC, 2008e). This is especially difficult with laundry appliances, as environmental savings are also economic savings in water, energy or detergent costs. Altruistic purchasing decisions for the environment are more evident in products with solely environmental features such as recycled content, which is not tied to other non-environmental benefits.

This study groups consumer organisations such as Altro Consumo in Italy and Öko Test in Germany under the 'consumers' driver. They play a role in conducting independent testing of various appliances to assist consumers in their purchasing decisions (PC, 2008o).

Electrolux also communicates environmental information to consumers, encouraging the efficient use of appliances to reduce impact during the use phase. Recent studies for the EU EuP directive conclude that user behaviour is the single largest determinant of the actual energy consumption of the washing process (ISIS, 2007b). An interviewee from R&D noted that a washing machine may be rated A+ in tests, but will achieve a G rating in the hands of the user (PC, 2008i). The ways in which users influence the energy efficiency of their washing machine include: load size, selected programme, selected temperature, and amount and type of detergent used. Clothing must be inserted with some force to reach capacity and consumers usually only fill washing machines to 64%, and dryers to 60% of capacity, resulting in significant inefficiencies (ISIS, 2007b; PWC, 2008b). Many washing machines are equipped with detectors to adjust parameters to the weight of the load but the most efficient cycle per kilogram of washing is at full capacity (ISIS, 2007b). The programme selected can have a significant impact, with interviewees from Marketing and Industrial Design noting that consumer confidence in the performance of the 'eco button' was low but improving (PC, 2008n; 2008u). The average washing temperature is 46°C, with some countries such as Spain averaging only 33°C due to their tendency to wash clothing in cold water (20°C) (ISIS, 2007b). Cold water washing is common in other parts of the world which are more likely to pre-treat stains, while Europe's need for a hotter wash without pre-treatment was said to be a result of culture and tradition by an interviewee from R&D (PC, 2008o). Automatic dispensers of detergent are an obvious solution to the common issue of detergent overdosing by the user, but as an interviewee from R&D explained they are not welcomed by the market (PC, 2008j).

Changing user behaviour is no easy task. In the words of one respondent: *"There are as many ways of doing the laundry as there are people in the world"* (PC, 2008e). Washing machines now come with 20 or so different cycles to cater to diverse consumer preferences. The design of the user interface is the prime medium for communication to users on how to wash more efficiently but has received less attention than measurable aspects such as energy consumption. Electrolux provides tips on efficient use of its appliances on its website, which have more attention now as they are integrated into the aforementioned Green Range campaign. Electrolux has also run special initiatives, such as a programme in Italy in collaboration with an NGO which involved the education of schoolchildren about environmental issues and their relation to appliances, and the distribution of 200 000 copies of a booklet on the efficient use of appliances (Electrolux, 2008b).

5.4.1.2 Customers

Customers are business purchasers of consumer goods and are often property development or property management firms who equip new and old apartments and houses with kitchen and laundry appliances. In other European countries customers make up a small percentage of sales but in Sweden for example they are particularly important, accounting for around 30% of total sales (PC, 2008e; 2008n). The Swedish Builders Association set up a program to 'Detox the Buildings', which was part of a movement in Sweden against the use of materials like PVC in appliances and was a factor in Electrolux eliminating PVC from its Swedish products (PC, 2008e).

5.4.1.3 Retailers

Retailers stand between Electrolux and Consumers, accounting for 74% of sales in Europe (Electrolux, 2008b). Local sales functions frequently meet with retailers, and while some interviewees highlighted the desire of retailers to stock the latest and most efficient products (PC, 2008o), others asserted that retailers generate far fewer requests for environmental features than Customers, who are relatively outspoken on such issues (PC, 2008e). In addition to traditional retail chains, IKEA has also been a retailer of Electrolux appliances. However, interviewees pointed out that it is a special case as the appliances can have bespoke IKEA designs and must meet especially strict requirements for environmental performance unseen amongst typical Retailers (PC, 2008g).

5.4.1.4 Competitors

While second to Whirlpool globally, Electrolux is the largest manufacturer of major appliances in Europe. Interviewees recognised its main European competitor as being the German firm Bosch, followed by Whirlpool (PC, 2008e). German Miele was also mentioned but competes only in high-end products alongside Electrolux's AEG brand (PC, 2008e). Electrolux has long been recognised as an environmental leader in the industry (Electrolux, 2002a), but competitors now address environmental issues thoroughly too.

5.4.2 Industry

This section covers those drivers beside of before Electrolux in the supply chain: Partners, Suppliers, Investors and Employees.

5.4.2.1 Partners

Electrolux collaborates with partners in various fields to gain expertise and resources not available in-house. A network of technical universities in Sweden, Germany, Italy and Russia develop and test new technologies, or assess current practices as with the aforementioned LCA studies (PC, 2008l). Partners from other industries such as automotive are also important according to interviewees, as they typically operate under higher margins and can be a few years ahead of major appliances in terms of technology (PC, 2008l).

5.4.2.2 Suppliers

Electrolux has 3 800 suppliers located around the world and its dealings with them are governed by the Electrolux Purchasing Policy (Electrolux, 2008b). This policy integrates both the Environmental Policy and the Electrolux Code of Conduct, which sets environmental and labour standards in the supply chain. The Environmental Policy states that Electrolux is committed to *"encouraging suppliers, subcontractors, retailers and recyclers of our products to adopt the same environmental principles as Electrolux"*. Suppliers communicate environmental information to Electrolux by developing and promoting new materials and components with lower environmental impacts. However suppliers could be said to have a smaller role in affecting the environmental performance of Electrolux products than in some other consumer durable industries. The outsourcing practiced among manufacturers in the electronics industry is not prevalent in the major appliances industry. The homogeneity of electronics equipment worldwide has allowed electronics manufacturers to increasingly centralise and outsource core product development functions, while major appliance manufacturers must adapt to diverse local market preferences, restricting the ability to outsource and centralise (PC, 2008c). This means that the Suppliers of Electrolux provide relatively simple components or materials instead of semi-finished products.

5.4.2.3 Investors

Electrolux is publically traded and investors have a key role in influencing the direction of the company. In 2007 an Electrolux survey of employees and investors about which environmental and social issues the company should report on revealed that nine of the top investors ranked climate change first, alongside environmental and labour standards in the supply chain (Electrolux, 2007d). The chairman of Investor AB, Electrolux's largest owner with almost 12% of the share capital, has spoken publically about the important role of energy efficient appliances in addressing climate change (Electrolux, 2008b). Interviewees explained that sustainability was high on the agenda for investors, who contact Electrolux with specific questions regarding certain substances in products (PC, 2008g).

5.4.2.4 Employees

Employees are within the firm but many are outside the product development process and are therefore considered as external drivers in this report. It was the opinion of interviewees that employees of the company are becoming more environmentally aware (PC, 2008c). Over 500 employees took part in the 2007 survey mentioned above, who also ranked climate change first (Electrolux, 2007d). Employees can communicate ideas to management through a web-based employee survey tool to which more than 10 000 employees contributed in 2007 (Electrolux, 2008b). More specific communication is facilitated through various means such as the "Suggest and Win" system used in Electrolux's washing machine manufacturing plants in Europe. Employees are encouraged to suggest improvements within four categories, environmental, quality, safety and process. The best suggestions receive prizes and are published on the factory notice board (PC, 2008k). However, these suggestions are invariably process-related and do not have much impact on product design.

5.4.3 Governance

This section covers those drivers outside the supply chain: Government and NGOs

5.4.3.1 Government

Government as a driver could take the form of regulation or incentives, and could act directly on Electrolux, or indirectly through influencing other drivers, such as Consumers through informative or financial measures.

Electrolux is affected by government at national and regional levels. In Europe, the greatest focus is put on government at the regional level, the European Union (EU). In recent years the EU has put in place a number of legislative measures to address the end of life treatment, chemical use in manufacture, and energy efficiency in use of major appliances. These are covered below in more detail. Electrolux advocates EU legislation over national measures as consistency across markets lowers the cost of compliance through standardisation and increased purchasing power (PC, 2008g).

Electrolux's interaction with EU legislators is channelled though CECED (European Committee of Domestic Equipment Manufacturers), the household appliance industry's trade organisation for Europe with 15 members representing 90% of the market (Bygge, 2006). CECED provides a forum for major appliance manufacturers to find common positions on legislation with which to lobby under collectively. The Electrolux environmental policy states that the company is committed to *"taking a proactive approach regarding environmental legislation that affects our business"*. Interviewees noted that in order to use environmental performance as a competitive advantage the company must go beyond regulations (PC, 2008f).

EU Energy Label

The EU Energy label (92/75/CEE, washing machines: 95/12/CE, 96/89/CE, dryers: 95/13/CE) stipulates that all major appliances on sale in Europe must display their energy rating. For washing machines the rating has three parts: energy consumption, washing performance and spinning performance, each rated from G up to A. The label also carries other information such as the spin speed, total water consumption, and noise levels. Dryers are only rated on energy consumption. Washing machines are tested using five swatches, each with a different stubborn stain: Egg yolk, soot, red wine, chocolate and blood. These are washed at full capacity on a 60°C cotton cycle and spun at maximum spin speed (PC, 2008f).

When the labelling scheme was introduced it was a discriminating factor, with washing machines ranging from E (≤0.35kWh/kg) to B (≤0.23kWh/kg) in energy efficiency. However manufacturers soon responded and now almost all machines achieve an A (≤0.19kWh/kg) rating for energy or better, resulting in A being a *"ticket to play"* in the words of one respondent (PC, 2008t). In an effort to standardise claims by manufacturers of better-than-A energy efficiency, manufacturers signed an agreement in 2004 preventing claims of an A+ rating unless efficiencies of 0.17kWh/kg were achieved. While a similar revision for refrigerators proposed by CECED (extending the label to A+ and A++) was accepted by the European Commission in 2003 (2003/66/EC), the revision for washing machines remains between signatories to the CECED agreement and therefore cannot be used on the product itself, only in separate promotional materials. A+ rated washing machines carry official energy labels stating A rated energy efficiencies.

The official EU label is expected to be revised by the end of 2008 and should come into force in 2010, addressing various shortcomings in the current label (PC, 2008d). It will test three different cycles instead of the single 60°C cotton cycle used in the current system and will include half-capacity loads to better simulate user behaviour (PC, 2008i; 2008j). Electrolux hopes it will be open-ended and numerical instead of letter-based and closed as is the current version, negating the need for updates which are costly, time consuming and confusing for consumers (PC, 2008d; 2008h).

WEEE Directive

The Waste Electrical and Electronic Equipment directive (2002/96/EC) is based on the concept of Extended Producer Responsibility and sets collection and recycling targets for different electrical and electronic equipment. Producers are collectively responsible for the recovery of appliances put on the market before the WEEE directive, and individually responsible for products on the market afterwards. Manufacturers are required to reach minimum recovery rates, a responsibility which should in theory create an incentive for Electrolux and other manufacturers to design washing machines that use fewer materials and less of them, as well as a higher proportion of recyclable materials.

RoHS Directive

The Restriction of Hazardous Substances Directive (2002/95/EC) restricts the use of six hazardous substances in the manufacture of electrical and electronic goods, namely; Lead, mercury, cadmium, hexavalent chromium and two groups of brominated flame retardants. From 2006 RoHS banned the sale of products containing these materials. The RoHS directive required the modification of many of Electrolux's products, mainly through the elimination of lead in solder (Electrolux, 2005b).

REACH

The Registration, Evaluation, Authorisation and restriction of CHemicals (REACH) is an EU Regulation (EC/2006/1907) mandating the testing of some chemicals. Electrolux does not deal directly with many of the chemicals in its products as they are embodied in components from Suppliers.

EuP Directive

The Energy using Products (EuP) ecodesign Directive (2005/32/EC) is a framework to harmonise measures to promote ecodesign in products across the EU. These measures are yet to come into force and are expected to do so in 2010 (PC, 2008d). At the time of writing background studies are being conducted, recommending directions for improvements in the ecodesign of EuP, which will be followed by impact assessment, consultation and eventual implementation.

Procurement Programmes

Procurement programmes are competitions set up by governments to encourage development of a product in a certain direction, often energy efficiency. The winner of such competitions is usually entitled to a grant or contract to supply the product to partners of the programme, which are often Customers such as property developers. Electrolux has entered procurement programmes at both the Swedish and European level since 1990 for appliances such as induction stoves, kettles, refrigerators, microwave ovens, and heat pump dryers, winning all but one (PC, 2008e; 2008g).

5.4.3.2 NGOs

As mentioned in Section 5.3.1, environmental NGOs such as Greenpeace have had a strong impact on Electrolux. Electrolux in Italy has had a 15-year partnership with the Italian World Wide Fund for Nature (WWF) involving the educational programme mentioned in Section 5.4.1.1 (Electrolux, 2008b). Media is another important factor but has not been included as a separate driver in this paper due to the involvement of NGOs in many of the most influential media events. An example is the aforementioned fridge dumping by Greenpeace, an action that resulted in coverage and pressure from the media.

5.5 Procedures

When producing a range of products in high volumes as Electrolux does, the management of the product development process becomes critical (PC, 2008h). Electrolux's management of the process utilises a procedure known internally as the Product Management Flow (PMF). Introduced in 2004, it is a form of stage-gate procedure developed by Electrolux and based on a procedure that had been used in the company since the early 1990s (PC, 2008f; 2008a). The previous procedure focussed heavily on the R&D and manufacturing functions of the organisation and did not involve marketing activities well (PC, 2008h). The introduction of the PMF was the culmination of a gradual shift from a company based on engineering principles, to one driven more by consumer needs (PC, 2008r; 2008t). The traditional arrangement saw the retailer standing between the manufacturer and the consumer, making direct consumer contact largely unnecessary, but in the last decades Electrolux has fostered a strong consumer orientation throughout the organisation. The PMF was designed to remedy shortcomings of the previous procedure by extending to cover a wider range of activities both earlier in the process (such as strategic planning and market research) as well as activities later on (such as the commercial launch of the product) (PC, 2008f). By including activities early on in the process the PMF was able to better assess reasons for beginning a new project. According to one interviewee this prevents simply developing to replace old products, an outdated method that results in continuous incremental improvements in established typologies (PC, 2008f). Instead it promotes development to meet the needs of the consumer whatever the typology, which in theory should allow radical in addition to incremental innovation. The PMF documentation resides on an internal network accessible to all, with information divided by stage and covering required activities, deliverables, proposed measures and best practices, contact people, among others (PC, 2008f). Adherence to each and every requirement within the PMF is not strictly mandated, allowing some flexibility in the development process (PC, 2008f). A simple depiction of the PMF is provided below.

Figure 5-1 Electrolux Product Management Flow

Source: Electrolux, 2008a

5.5.1 PMF Stages

The PMF comprises nine stages. A project may or may not cover all nine, depending on its complexity (PC, 2008j).

The **Strategic Market Plan** outlines the perceived business opportunities and is developed through research into consumer trends (such as consumers demanding dual-input washing machines), industry trends (which might be increases in the market penetration of dryers), and macro trends (such as climate change and increasing environmental awareness) (PC, 2008t).

Identification of Consumer Opportunities entails extensive market research involving customer interviews, focus groups, field trials, home visits or other methods to identify areas of business opportunity. These opportunities could be in managing consumers' time, or perhaps in environmentally friendly products for example. The product of this stage would be a collection of ideas as to how to potentially address these opportunities (PC, 2008t; 2008n).

Concept Development involves input from various functions and aims to develop on the collection of ideas, evaluating and filtering them down to a small handful worth spending further resources on validating with further customer interaction (PC, 2008n). By shelving less feasible ideas and developing on more feasible ones, Concept Development reduces the business risk of the project (PC, 2008j). Once a single concept has been selected and validated a project proposal is produced for the Product Development stage.

Primary Development does not necessarily feed directly from the stage before it. It develops hardware solutions for use in the Product Development stage that might not be attached to any one project, but potentially applicable to many. This reduces the technical risk of new technologies (PC, 2008j).

The **Product Development** stage takes input from Concept Development and Primary Development, transforming the project concept and hardware solution into verified product specifications and plans for industrialization and launch, ready for manufacturing.

Commercial Launch Preparation translates the output of concept development into a marketing message for the consumer. **Launch Execution** involves the distribution and commercial launch of the product and marketing campaign. **Range Management** is the management of products once launched, entailing updates and market feedback. **Phase-out** is the contracted collection of used machines for recycling.

5.5.2 Checkpoints

Beneath the Product Development stage presented above lies a more detailed stage-gate procedure with checkpoints (CP). The most crucial of these checkpoints is the third in the procedure and is known as CP0. It is the point where the product specification, product design and costs are frozen and the launch date for the product is fixed. The procedure mandates an environmental analysis in the step before CP0 (during the translation of concept into specification), and afterward (during the engineering of the product and manufacturing process). One interviewee was of the opinion that cross-functional team members sometimes perceived environmental requirements in the procedure negatively, as a "rubber stamp" needed to proceed instead of an opportunity (PC, 2008t).

5.5.3 Cross-Functional Teams

The process necessitates the formation of cross-functional teams from the beginning of a project. Usually 4 or 5 people make up the core members with others involved as non-core members or as consultants to the team. Teams will typically consist of people from product division or line-level functions (or function groupings) such as Marketing, R&D, Industrial Design, Sales or Manufacturing ('functions' differ from 'stages' in the procedure and are covered in the next section) (PC, 2008n; 2008j; 2008i). Functions on Group and European levels are typically involved as non-core members or consultants. The composition of teams depends on the project and the stage of development it is in. Environmental Management functions do not typically have staff within cross-functional teams, and instead are brought in as consultants (PC, 2008v). One respondent from Industrial Design mentioned that while it would be nice to have staff from Environmental Management in each cross-functional team, there would not be enough to go around and instead staff from other functions must provide on-hand environmental knowledge (PC, 2008u). Environmental expertise within the teams generally resides in technical staff that would recognise potential environmental risks through environmental assessments and initiate contact with Environmental Management functions accordingly (PC, 2008i). A respondent from R&D explained that correspondence with Environmental Management functions was common, especially when market and environmental requirements collided (PC, 2008i). A respondent from Environmental Management noted that in some cases they in fact initiate their own involvement in cross-functional teams after hearing about the proposed use of a certain substance (PC, 2008v). It was the opinion of a respondent from Marketing that Environmental Management's involvement in teams as a consultant was perceived as reactive in nature, which compounds the common issue of Environmental Management being perceived by other functions in an organisation as 'police' or 'gate keepers' (PC, 2008t).

5.6 Functions

This section describes the different functions in Electrolux, where they fit in the PMF procedure, their roles in the innovation process and in communicating environmental information. The section first covers the Marketing function grouping, then the R&D grouping, the Environmental Management grouping and lastly the other functions involved. Like the drivers section, this section also covers the type of environmental information being communicated, which is part of the procedure variable in the analysis but is best explained in this section.

5.6.1 Marketing

Marketing functions in Electrolux are spread across the levels of Group, Europe and Product division. The Marketing function contained within the Product Line Management function is closest to the innovation process and for this reason has been chosen to represent the Marketing function in this study. Product Line Management operates on both the product division level and product line level and is the only function with a detailed overview over the entire PMF. It is responsible for the commercial success of the company's product offerings and therefore has significant influence on the direction of product development. Due to the combination of roles, Product Line Management and the Marketing function it contains are referred to as Product Line Management and Marketing in further discussion.

Product Line Management and Marketing is involved from the very beginning, setting strategic marketing plans according to directions set by Group Management, identifying consumer opportunities, setting long term plans for product line development and participating in cross-functional teams in developing concepts (PC, 2008j; 2008t). It also conducts competitor analyses and collects detailed information about consumers (PC, 2008t). Product Line Management and Marketing connects the R&D functions with Industrial Design, Manufacturing and Sales and is therefore a focal point for flows of environmental information. The Europe level environmental management function of Environmental and European Affairs provides information on proposed legislation and expertise in technical environmental issues, while the Group level environmental management function of Group Sustainability Affairs is a source of knowledge on topics such as LCAs. Product Line Management and Marketing influences and is influenced by the work of the R&D functions and Industrial Design, and although the connection with Manufacturing is strong it is not a flow of environmental information as Manufacturing is not heavily involved in the development process. Sales provides Product Line Management and Marketing with information from Retailers and Customers, while information from Consumers is gained directly and sometimes through the Consumer Innovation Programme function, explained below. Marketing also influences consumers' efficient use of appliances through usage tips.

5.6.1.1 Consumer Innovation Programme (CIP)

The Consumer Innovation Programme is a group function, which works with the cross-functional teams in the development process. It provides organisational know-how, assisting teams in developing concepts and exploring new ideas which functions on the product division or line level may have little experience with (PC, 2008i). The CIP also provides Product Line Management and Marketing with information on customer needs from more general market analyses that individual product divisions or lines do not perform (PC, 2008j) such as the survey on environmental preferences mentioned in Section 5.4.1.1.

5.6.2 Research and Development (R&D)

This study uses the term R&D to encompass all core technical development functions. At Electrolux this means Product Development, Primary Development, and Core Technology and Innovation (CTI). In some organisations Product Development could be discussed separately from R&D, but in Electrolux Product Development has significant research capabilities so is grouped with the other R&D functions.

5.6.2.1 Product Development

Product Development is a relatively large function, operating on both the product division and product line levels, and is a key function in the Product Development stage of the PMF. Its central role is turning product concepts into mechanical designs ready for manufacturing. By the time Product Development begins work on a project, the features, functions and form of the product have been decided, Product Development's role is to compose the machine with components purchased from the market and occasionally with hardware specially developed by Primary Development (PC, 2008h). Different assortments of components are combined inside a common platform to create different models with different performances and efficiencies. The function also includes laboratories where technologies are developed and proposed to Product Line Management and Marketing (PC, 2008i). Product Development has frequent collaboration with Primary Development and CTI in developing technologies, while Industrial Design works with Product Development in determining materials and other components affecting aesthetics and usability. Product Development relies on Environmental and European Affairs to provide information on relevant legislative developments (PC, 2008h) and although a strong communication channel exists between Product Development and Manufacturing, it is not considered a flow of environmental information for the reasons given in Section 5.6.1.

5.6.2.2 Primary Development

Primary Development is a function on the product division level, which develops technologies for use in Product Development. These technologies are more radical in nature and require the work of Primary Development to reduce uncertainty to the level where they can be utilised by Product Development, where a specific date must be set on which to launch the product (PC, 2008i). The Primary Development function fulfils the Primary Development stage in the PMF, while also lending itself to the Concept Development stage (PC, 2008i; PC, 2008j). A respondent from Primary Development noted that involving environmental issues at the industrialisation stage (after specification) of a project is too late and that functions like Primary Development have great flexibility to bring about environmental improvements because of their influence early in the process (PC, 2008i). Primary Development relies on Product Line Management and Marketing to keep it informed about consumer preferences, however it was stressed that they cannot simply ‘wait for instructions’ and instead must actively conceive, develop and propose ideas in a continuous dialogue with other functions (PC, 2008i). Primary Development exchanges technical information with CTI and Product Development, and collaborates with Partners such as universities in developing new technologies. They receive information on relevant legislation from Environmental and European Affairs as well as advice on potential environmental impacts of new technologies (PC, 2008i).

5.6.2.3 Core Technology and Innovation (CTI)

CTI plays a similar role to that of Primary Development, but is a Group-level function working across all product lines. It sits outside the PMF, providing assistance to Product Development and Primary Development where needed. CTI communicates with Marketing functions to keep updated on general trends, and is often involved with Partners whether they be universities, research institutes or corporations in other industries (PC, 2008l). Partners were recognised by an interviewee in CTI as a crucial element in innovation due to the limited capacity in-house and the potential for knowledge gain outside the company (PC, 2008l). Traditionally CTI has operated like an internal consultancy to other functions, but in recent years there has been a push to develop its own capacity for innovation (PC, 2008o). It is currently working on an environmental-focussed project looking at various eco-innovations from single appliance efficiency to integrated systems much like Whirlpool’s “Green Kitchen” concept. Electrolux is the only major appliance manufacturer in the European Committee’s “Address” interactive energy programme which looks to utilise smart meters to manage electricity demand more efficiently.

5.6.3 Environmental Management

Electrolux has two functions for environmental management in Europe, Group Sustainability Affairs at the Group level and Environmental and European Affairs at the European level. Neither fit directly into the PMF but both are involved through consultation with cross-functional teams. Both functions were established in the last few years by a division of the previous group-level Environmental Management function.

5.6.3.1 Group Sustainability Affairs

Group Sustainability Affairs operates globally developing and issuing policies regarding environmental issues. Examples of such policies are the Environmental Policy, the

Restricted Material List and the Electrolux Code of Conduct. Each region is responsible for the interpretation and implementation of these policies (PC, 2008g), and in Europe it is the job of Environmental and European Affairs (PC, 2008c). Significant interaction between Group Sustainability Affairs and Environmental and European Affairs is necessary in developing policies to ensure compatibility with legislative and technical matters (PC, 2008c). Group Management is consulted to determine the direction of the policies and resolve conflicts when environmental and business goals are not aligned (PC, 2008g). Group Sustainability Affairs is involved in checking supplier compliance to the Electrolux Code of Conduct, and communicates with investors, NGOs, and International Organisations and related programmes (PC, 2008g). Another responsibility is providing assistance to production facilities in implementing and maintaining their EMSs (PC, 2008g). Group Sustainability Affairs is a key source of knowledge on LCAs and was involved in the removal of PVC from products in Sweden (PC, 2008g).

5.6.3.2 European and Environmental Affairs

Based in Brussels, Environmental and European Affairs deals with legislative and technical environmental issues. A key task is following proposed legislation coming from EU or national governments, where proposals are assessed for their impact on Electrolux and summaries are provided to the Product Line Management and Marketing function as a strategy proposal (PC, 2008d). From there interaction ensues between Environmental and European Affairs, Product Line Management and Marketing and Product Development in working groups to establish a company position on the proposed legislation. This position is then communicated to other members of CECED where a common industry position is sought and lobbied with in an attempt to steer the proposed legislation.

As explained above, Environmental and European Affairs is involved in the development and implementation of corporate environmental policies, providing an important step between the broad goals of corporate policy and practical operational measures (PC, 2008c). Environmental and European Affairs is the European organisation's source of knowledge on technical environmental or legislative issues and is consulted by cross-functional teams when an environmental risk is identified (PC, 2008t; 2008i; 2008v). It is the opinion of one respondent from Environmental and European Affairs that the recent promotion of the Green Range has provided more common ground between Environmental Management and Marketing functions, making it possible for Environmental and European Affairs staff to participate to a limited extent in strategic Green Range meetings, providing advice on making marketing messages more accurate, meaningful and deliverable (PC, 2008v).

5.6.4 Other

This section covers Group Management, Industrial Design, Manufacturing and Sales

5.6.4.1 Group Management

Group Management determines the strategic direction of the organisation, and is not directly associated with the PMF or innovation process. Electrolux's environmental achievements over the last 15 years have been underpinned by continued leadership from Group Management in this direction. Public materials for both internal and external audiences commonly feature statements from the CEO strongly endorsing the environmental direction. When making strategic decisions about environmental issues, Group Management is directly influenced by Investors with environmental agendas, and assisted by the aforementioned Group Sustainability Affairs.

5.6.4.2 Industrial Design

Industrial Design is a Europe-level function, with managers assigned to different product divisions (PC, 2008s). It is integrated across various stages in the PMF; often participating in Product Line Management and Marketing's consumer research projects during the Identification of Consumer Opportunities stage, assisting in putting together concepts in the Concept Development stage, and working with Product Development in the initial phases of the Product Development stage to put together the exterior design. Designing the exterior panels and aspects of the inner drum is the main function of Industrial Design for washing machines – a product with predetermined dimensions and without much design freedom in terms of form and materials.

But while Industrial Design's traditional focus has been only on aesthetics, usability has become a key competence in recent years (PC, 2008n). Through designing the user interface Industrial Design has a significant influence on how the user operates the machine, and therefore on the real-life environmental performance. However, examples to date of Industrial Design positively and intentionally influencing the user's efficient use of the machine were not found. It should be noted that measuring the success of such efforts would be very difficult. While Industrial Design is present in many cross-functional teams, its role in influencing the environmental performance of washing machines was seen by one interviewee to rely on direction from Product Line Management and Marketing (PC, 2008s). Another interviewee from Industrial Design noted that while material choice is a domain of Industrial Design, when Industrial Design becomes involved in a project the decisions on materials will often have already been made by the Product Development and other functions (PC, 2008u).

5.6.4.3 Manufacturing

Manufacturing operates on the product division and product line levels, and its primary task is to take over projects from Product Development and assume final responsibility for launching the product on the market. Manufacturing fits into the PMF in the late phases of the Product Development stage and in Commercial Launch Preparation and Launch Execution. Manufacturing only looks at processes, and a product's level of efficiency has no influence on its manufacturing unless it involves a radically different technology (PC, 2008k).

5.6.4.4 Sales

Within the PMF Sales is generally involved in Commercial Launch Preparation and Launch Execution, coordinating the launch and local promotional activities. Sales deals with Customers and Retailers on a day to day basis, communicating their demands for environmental performance through to Group Sustainability Affairs and Product Line Management and Marketing.

5.7 Success Factors

Although some of the six success factors selected for analysis have been covered in the three previous sections on drivers, procedures and functions, this short section revisits the six factors and explains those not yet touched upon.

5.7.1 Management Commitment

As explained above in Section 5.3.1, the commitment of Group Management is strong and well communicated both internally and externally. Interviewees explained the clarity of the environmental message and the personal involvement of the CEO in communication (PC, 2008j).

5.7.2 Ecodesign Training

An ambitious ecodesign training programme for white-collar employees was undertaken for two years following the introduction of the Natural Step in 1994 (PC, 2008n; 2008e), but has since ceased in all but a few parts of the organisation, such as an operational unit in Switzerland (PC, 2008v). Training for blue-collar employees on the other hand is well implemented but is unlikely to affect the eco-innovation process (PC, 2008k). Interviewees in Primary Development and Industrial Design did not believe the lack of training was an issue, explaining that ecodesign training came "on the job" (PC, 2008i) and that environmental considerations are "baked into" the PMF procedure making it everyone's responsibility (PC, 2008u). Other respondents from Sales and Product Line Management and Marketing suggested more ecodesign training in some form could be a good thing (PC, 2008e; 2008t). In conducting interviews and discussing environmental issues with 19 employees throughout various functions, a personal observation was made that almost all interviewees exhibited a sound understanding of the significant environmental aspects of the products. However, most interviewees had been in the firm for many years and held senior positions, which may have positively influenced their environmental awareness. The data collection did not attempt to 'test' the level of environmental awareness among staff, and it is unclear as to how a newly hired employee would acquire awareness about relevant environmental issues and how to address them. It is also unclear as to whether the previous training has been absorbed into the corporate culture of the organisation or if it has been forgotten. The first situation could be argued to be the goal of environmental education in firms, that it becomes ingrained and no longer considered a special issue. On the other hand it may have been forgotten and simply boiled down to rhetoric. As this study is more than 10 years after the end of the ecodesign training period, it is assumed that the success factor of ecodesign training is absent in the Base Case (in accordance with the assumption outlined in Section 4.1.2.4).

5.7.3 Environmental Champions

Environmental champions outside Environmental Management functions who are recognised as such are few within the organisation. This study came across three such people based in Sweden and Switzerland, two of whom were interviewed. Environmental champions are said to foster awareness and enthusiasm about environmental aspects, and although champions in Electrolux seemed few, the enthusiasm was evident among other employees. An interviewee from the Primary Development function jokingly proposed that a search of his computer for common words would yield 'innovation' and 'environment' as the top results (PC, 2008i). This however is no measure of the true enthusiasm towards environmental issues in real working situations, which presents a potential topic for further research.

5.7.4 Access to Environmental Specialists

As mentioned in Section 5.5.3 above, any cross-functional team or function involved in the innovation process is able to consult environmental expertise in Environmental and European Affairs. Access would obviously be greater if an environmental specialist was integrated in the cross-functional team as a member.

5.7.5 Cross-Functional Teams undertaking Ecodesign

As explained in Section 5.5.3, cross-functional teams are standard in the PMF procedure.

5.7.6 Environmental Mindset

As covered in Section 5.3.1, the business case for environmentally friendly products is well recognised by Electrolux.

6 Product Cases

In this section the five Product Cases are presented, consisting of the A+ energy rated washing machine, the Heat Pump dryer, the Sunny dual-input washing machine, the Iron Aid dryer, and Functional Sales Product Service System (PSS). Each case describes the product, its environmental aspects, key drivers and functions, the development process, success factors and relevant barriers.

6.1 A+ Energy Rated Washing Machine

6.1.1 The Product

Electrolux's annual European production of washing machines sits at about 3.6 million units, most of which are both front-loading and A+ rated for energy efficiency (PC, 2008a). Of the 19 washing machines making up the Swedish line in August 2008, 16 were rated A+ for energy and the remaining three A (Electrolux, 2008c).

The energy efficiency with which a washing machine removes dirt from clothing depends on four key variables; its three sources of energy, and time. The energy used in washing clothing can be divided into thermal, kinetic and chemical, representing the water temperature, mechanical agitation and detergent, respectively. The length of the wash determines the time in which the chemical energy can act. These parameters can be configured to achieve the maximum efficiency of the machine. Generally speaking, thermal and chemical energy are often overdosed, while kinetic energy and time are under-dosed, resulting in significant inefficiencies (PC, 2008; 2008j). The energy label is determined with a fixed level of thermal energy (60°C) and does not represent the maximum efficiency achievable by a machine.

An A+ energy rated front-loading washing machine will use 0.17kWh or less to wash each kilogram of clothing when filled to capacity using a 60°C cotton cycle, while an A rated machine uses ≤0.19kWh (Electrolux, 2007a). A++ machines, while completely unofficial, will soon hit the market using ≤0.15kWh/kg (PC, 2008t). The developments that have lead to these gains have been in using more efficient motors, increasing capacity, optimising cycles and minimising the clearance between the inner and outer washing drum, reducing water use and the energy needed to heat it.

Washing machines come in standardised dimensions and are developed using platforms, where a variety of models are created using different combinations of features on the same base machine. This is how Electrolux determines the specific efficiency of a machine, weighing cost against efficiency in choosing a set of components and features to apply to the platform.

6.1.2 Environmental Aspects

As explained in Section 5.3.2.2, LCAs indicate that the vast majority of a washing machine's impact is associated with the use phase, a common feature across the entire range of energy-using products Electrolux produces. Electrolux estimates that if all European appliances over 10 years old were immediately replaced with the latest versions, annual European emissions of CO_2 would decrease by 18 million tons, the equivalent to 6% of the EU's goal under the Kyoto Agreement (Electrolux 2008a).

6.1.3 Drivers, Functions and Development

In developing A+ energy rated washing machines, interviewees mentioned consumer demand as a central driver (PC, 2008e; 2008i; 2008o), especially in markets such as Germany, France and Sweden where the A+ rating is now so common it is not a differentiator (PC, 2008i; 2008t). Consumer needs are assessed by Product Line Management and Marketing. Consumer Organisations also acted as drivers according to one respondent (PC, 2008o), conducting tests that rank appliances more effectively than the EU labelling scheme, where virtually all washing machines are rated A or A+ for energy.

Competition amongst manufacturers provided a strong driver according to some interviewees, with A+ rated washing machines now common to all major manufacturers in Europe (PC, 2008o; 2008e; 2008d). In developing new products, competitor assessments are common and are coordinated by Product Line Management and Marketing.

Retailers reacting to consumer preferences for efficient appliances were also mentioned as drivers, occasionally requesting the most energy efficient washing machines. Retailers are dealt with by the Sales function (PC, 2008o).

Government was not seen as a strong driver due to the fact that the official EU labelling scheme only extended to A, and consumers were confused by the claim of A+ which contrasted with the A displayed on the official label (PC, 2008o). Therefore, Government alone was not sufficient in driving washing machines beyond the maximum A energy rating. It did however establish a means of comparison between machines, which lead manufacturers to pursue greater efficiencies in the first place.

The Product Line Management and Marketing function was seen to be integrated from the beginning of the process. The Sales function was involved in simply transmitting environmental information from Retailers on to Product Line Management and Marketing.

As the development of the A+ rated washing machine followed the typical procedure, the evident success factors are essentially identical to that of the Base Case.

6.1.4 Barriers

A barrier to the development of the A+ rated washing machines was that the labelling scheme didn't officially accommodate efficiencies higher than A.

6.2 Heat Pump Dryer

6.2.1 The Product

The Heat Pump dryer was introduced to European markets on a large scale under the AEG brand in 2005. It was in fact developed and sold long before that but in very small numbers and at a high price. The product is based on a regular condenser tumble dryer, meaning the hot water-laden air is not vented outside the house but condensed to remove the water then released into the house. What differentiates it from other condenser dryers is that it uses a heat pump to dramatically increase its energy efficiency. The heat pump works much like a refrigerator, using a refrigerant to suck in low temperature ambient heat such as that coming out of the dryer, and increase its temperature before feeding it back into the drying system. Electrolux is the only major manufacturer with a heat pump dryer on the market. Bosch and Miele are expected to release competing products in the coming months (PC, 2008m; 2008t).

6.2.2 Environmental Aspects

No matter how efficient a dryer is it will never compare with hanging clothes out to dry. However, if a dryer is to be used, the Heat Pump dryer delivers 40% energy savings over regular condenser tumble dryers. It is A rated for energy, but goes well beyond the A rating criteria of ≤0.55kWh/kg, consuming only 0.31kWh/kg. The best condenser dryers achieve a B rating of ≤0.64 kWh/kg, and when the Heat Pump dryer was released the next most energy efficient dryer had a C rating (Electrolux, 2008e). The Heat Pump dryer also dries clothing at a lower temperature than regular condenser dryers, extending the life of frequently dried items (PC, 2008o; 2008t).

6.2.3 Drivers, Functions and Development

One of the main drivers mentioned by interviewees for the initial development of the heat pump dryer was a Swedish government procurement programme in 1996. It promoted the development of highly efficient dryers and stipulated that the winning machine must be a tumble dryer using half the energy of typical machines and available for a certain low price (PC, 2008g; 2008e). The former equivalent of the current Group Sustainability Affairs department was involved in communicating the idea to enter this programme to teams in the Product Development research divisions. The Electrolux Heat Pump dryer was the winner of this programme and has since been developed into a commercial product.

An essential component of the procurement programme was a contract to supply participating Customers (such as developers and property management firms) with the winning machine. This points to Customers as a potential driver of the Swedish government in setting up the programme.

Heat pumps are far from a new technology, being common in industrial applications and domestic air conditioning. However, the commercially successful application of the technology to tumble drying is a relatively new, even if a patent was filed for such a concept decades ago. The high cost of production and design of such a product postponed the innovation until Electrolux's attempt in the mid 1990s (PC, 2008g). In order to make the Heat Pump dryer come in under the price set by the programme, Electrolux initially took a loss on each product. Such a money–loosing venture was hard to sell to the rest of the organisation and therefore the concept never saw mass production in its original form. The product continued to be produced, but in small numbers, at very high prices and manufactured by hand.

In the Heat Pump dryer's eventual commercialisation in 2005 consumer demand was seen as a key driver (PC, 2008o). This was a decision from Product Line Management and Marketing to release the product at a lower price than it was offered for previously and capitalise on the recent trend for energy efficient appliances. The Heat Pump dryer's mass production required significant investments in tooling due to the complex technology involved (PC, 2008t). But even though the product was priced significantly higher than other condenser dryers it was a commercial success (PC, 2008l). The innovation process therefore essentially saw two stages: The innovation (where it was conceived, developed and sold in small numbers) and the diffusion (where it was commercialised properly on the market more recently). The analysis is concerned with the innovation process and therefore focuses on the earlier stage only.

Interestingly, the Heat Pump dryer was eventually marketed more for its lower drying temperature, which allowed it to dry delicate items such as wool or silk. Energy efficiency took a back seat to gentleness in marketing campaigns, a focus which gave the product added value as a high cost item, with efficiency acting as an additional benefit (PC, 2008t).

Due to the product being developed more than a decade before the interviews were conducted, it was difficult to reliably ascertain the existence of the six success factors. However it is reasonable to assume that ecodesign education was strong, as the project began soon after the training program ended, and that both top management commitment and an environmental mindset were strong due to Electrolux having implemented a proactive environmental strategy only a few years before.

6.2.4 Barriers

The key barrier in developing the Heat Pump dryer was its cost, preventing it from being mass produced and reaching the market before a large segment of consumers became willing to pay a significantly higher price for greater energy efficiency.

6.3 Sunny Dual-Input Washing Machine

6.3.1 The Product

The Sunny washing machine was introduced in February 2008 to the Italian market under the Rex brand and has proven a commercial success. The product itself is a standard A+ rated Electrolux front-loading washing machine with an input for hot water in addition to the standard input for cold. This is a common feature among top-loaders in North America and Australasia, allowing the hot water to come from a more efficient domestic supply instead of being heated with electricity within the washing machine, as it is in all European machines. This more efficient source of domestic hot water could be district heating, a home boiler or solar heating. The Sunny is commonly sold with roof-mounted solar heating panels, the configuration from which it gets its name. Electrolux is the first and currently the only manufacturer to offer such a solution in Italy. It is this configuration that this study uses as a product case.

6.3.2 Environmental Aspects

The washing machine still has the ability to heat water inside the machine, and is rated as a standalone product under the energy labelling scheme, achieving ratings typical to Electrolux front-loaders of A+, A and B for Energy, washing, and centrifuge respectively. However, when drawing hot water from solar water heaters the Sunny can achieve up to 40% savings in energy use (Electrolux, 2008b).

6.3.3 Drivers, Functions and Development

A key driver in the development of the Sunny mentioned by all respondents was consumer demand in Italy, much more so than the previous case (PC, 2008t; 2008l). Consumers were so outspoken about the idea that they made frequent requests to the call centre demanding a product able to use hot water from solar heaters. (Electrolux, 2008d; PC, 2008t). This was seen to be due to the high price of electricity, government incentives encouraging the installation of solar heating in homes (PC, 2008t), electrical restrictions in Italian homes limiting the simultaneous use of several appliances (PC, 2008e), and the availability of sun and solar heating solutions in the country. It could be argued that the government was a partial driver of the consumer driver in this case through initiating financial incentives towards solar heating.

Product Line Management and Marketing interpreted the market potential of the Sunny and brought the concept to Product Development (PC, 2008i). Technically the Sunny could leverage from dual-input washing machines sold by Electrolux in the U.K. years earlier (PC, 2008k). The low-technology Sunny did not involve research-orientated functions such as Primary Development and Core Technology and Innovation, and according to some respondents it did not hold high importance among Product Development despite Product Line Management and Marketing's enthusiasm for the concept (PC, 2008l; 2008i).

The development of the Sunny follows the typical procedure, and like the A+ rated washing machine the prevalence of the success factors appears identical to that of the Base Case. There were no significant barriers identified in the development of the Sunny.

6.4 Iron Aid Steam Dryer

6.4.1 The Product

The Iron Aid is an unconventional laundry product launched in the European market in the last few years. Essentially a condenser tumble dryer with a steam-generating unit inside, the product offers a broader range of functions than a typical dryer with special programmes utilising the steam to remove wrinkles and odours from clothing. As a tumble dryer – the category under which the product is sold – the Iron Aid was rated C until an upgrade in 2008 giving it a rating of B with 0.56kWh/kg. The C rating put it behind many other tumble dryers on the market, when the true environmental benefits of the product come from its substitution of ironing and washing, which are not included in the rating.

6.4.2 Environmental Aspects

In a 20-minute programme using 0.2kWh, the Iron Aid is able to de-wrinkle 5 shirts (Roggerna, 2007) while Electrolux studies show that ironing shirts by hand would result in greater energy use (PC, 2008i). The Iron Aid is highly effective in removing wrinkles but is not said to replace the iron completely, with some garments possibly requiring additional pressing. By removing odours from clothing the Iron Aid replaces the need to wash clothing that is not stained or soiled, but not clean either. 'Not clean but not dirty' washing constitutes a large part of many consumers' washing loads, and by 'freshening' these items in the Iron Aid, a full washing – and potentially a drying – cycle is avoided. This could result in significant savings in energy and water consumption, but has yet to be properly tested in an LCA.

6.4.3 Drivers, Functions and Development

A key driver for this innovation mentioned by respondents from R&D functions was an idea from Product Development to integrate steam technology into the consumer product lines (PC, 2008i; 2008o). Electrolux had experience working with steam in its professional laundry line, and therefore had the resources to develop a type of product not yet seen on the consumer market. In Product Development laboratory researchers often explore ideas based on their general interpretation of consumer needs. In the Iron Aid case it was well understood that there was significant commercial potential in replacing the over-washing of 'not clean but not dirty' garments or the ironing of garments by hand (PC, 2008o; 2008i). This acquisition of new technological knowledge is not taken into account in the drivers variable in this paper because its source is internal. It is instead represented by Product Development being an involved *function*.

One respondent from Product Line Management and Marketing saw consumer demand as a driver and described the development as a convenient merger of both Marketing's desire to use steam for cleaning, and Product Development's breakthroughs in the technology (PC, 2008t). But as the product concept was entirely new, demand did not manifest as a desire for a dryer that could iron and freshen. Market research identified a strong consumer dislike towards ironing, with 60% of consumers saying they 'hate it'. Marketing tested the concept of steam with consumers with positive results and set about commercialising the concept (PC, 2008t).

A cross-functional team was set up to refine the concept, involving various functions in addition to Product Line Management and Marketing and Product Development (PC, 2008i). Primary Development was involved in evaluating the performance (PC, 2008i).

No difference was found in the prevalence of the success factors from that of the Base Case with the exception of ecodesign training. The development process for the Iron Aid began within 10 years of the end of the training program, so this study will assume that the influence of the training was minor.

6.4.3.1 Ironing VS Washing Substitutions

When developing the Iron Aid concept, Product Development were initially more focussed on the washing substitution than replacing ironing, explained one interviewee (PC, 2008o), but when launched on the market a single message was chosen for clarity (PC, 2008i). Although Product Development had devoted more research to the washing substitution and believed this to be the core function of the product, the research done by Marketing indicated that the ironing substitution had a stronger message to consumers (PC, 2008o). As the product offers two functions previously unseen in a dryer but is categorised amongst regular tumble dryers, it was seen as important to avoid confusing the consumer with multiple messages (PC, 2008i). The ironing direction was taken and the product became the Iron Aid. Brief LCAs were conducted to assess the environmental benefits of using the Iron Aid instead of an iron (PC, 2008i).

This approach stands in contrast to competitor products launched after the Iron Aid. Instead of a steam-assisted dryer, Whirlpool and LG have opted to add steam to a washing machine and focus much more on the washing substitution as a marketing message (PC, 2008e). However, after a couple of years on the market, the Iron Aid is beginning to catch on and become more familiar to consumers (Roggerna, 2007), potentially opening the door for the washing substitution to be used as a marketing message (PC, 2008n).

Despite the potential environmental benefits of washing and ironing substitution, the Iron Aid is not currently marketed as an environmentally friendly product (PC, 2008n). This is due in part to the issues in adding yet another message to a marketing campaign, and perhaps because until 2008 the product did not have a favourable energy rating.

6.4.4 Barriers

A central barrier to the development of the Iron Aid was the difficulty in introducing two new functions within an established product category (PC, 2008n; PC, 2008i). The market perceives the product as a dryer with an additional feature and is not ready to accept ironing or washing substitution as a central function (PC, 2008n).

6.5 Functional Sales Product Service System (PSS)

6.5.1 The Service

In a marked deviation from its traditional business model, Electrolux partnered with the Swedish state energy company Vattenfall in 1999 to test a Product Service System (PSS) entitled Functional Sales. It was the first such system in the world to provide consumers the service of washing in their own homes instead of the product of a washing machine. The project took place on the Swedish island of Gotland, where Vattenfall had already installed smart meters in 7 000 households as part of a separate project.

The customer would pay €50 to have Electrolux install the washing machine in their home. The washing machine would be connected to the home's smart meter, which would measure how much electricity was used by the machine. The customer would be charged €1 per 'cycle'. A cycle was defined as 1kWh used by the machine, equivalent to a little less than one cycle at 60°C. Electrolux would retain ownership of the machine and service it as needed. Consumers had the ability to switch between models and sizes of machines for just the installation cost. After 1 000 'cycles' Electrolux would replace the machine with a new one, and use the retired machine for refurbishment, parts, or scrap.

Despite positive results from initial market research, the uptake of consumers during the project's first year was very low, and in 2000 the project was closed (PC, 2008r). However, even as a commercial failure this case can still be analysed for its innovation process.

6.5.2 Environmental Aspects

A PSS such as this has numerous environmental benefits over the traditional product system. By retaining ownership of the machine and providing servicing, Electrolux is able to ensure the machines are modern and operating efficiently, saving energy, water and extending their service lifetimes. Once retired Electrolux is able to collect the machines and refurbish them for use within the system or for sale on the second-hand market, preventing waste and resource use in producing new machines. By paying for both the energy and the service of the washing machine by kWh, users have an incentive to optimise their use of the washing machine by filling it to capacity and washing at a lower temperature. This incentive is enhanced by alerting the user to the exact cost of the service when they wash, as opposed to the traditional product system where a user would have to calculate the purchase and energy prices themselves to reach a per-cycle price. Electrolux calculated significant savings in energy, water and detergent if washing machine PSSs became common (10% penetration) in Europe, their calculations can be found in Dudda and Thomas (2001).

6.5.3 Drivers, Functions and Development

Function Sales began as an initiative from the corporate level lead by the corporate environmental manager – who would be in Group Sustainability Affairs if it had existed at that time (PC, 2008r). The environmental benefits of the system were clear and a corporate desire to test the scheme as an environmental measure was a seen as an important factor. The system also had economic benefits in the efficient management of washing machines without relinquishing ownership (PC, 2008r). Vattenfall – who had installed the smart meters – was a partner in the project and acted as a driver in its desire to test its meters in such a system. The Wuppertal Institute was also a partner and assessed the project alongside a small number of proposals for similar projects in other European countries (PC, 2008r).

Before the project was undertaken, a market analysis was carried out to test consumers' acceptance of the concept. 650 households were interviewed by telephone, yielding promising results indicating that over 40% of households had an interest in the concept (Dudda & Thomas, 2001). Electrolux chose its most efficient machine at the time and with minor modifications from R&D to integrate the machines with Vattenfall's smart metering system they were ready (PC, 2008r).

The evident success factors deviated form those of the Base Case in three ways. Due to the deep involvement of the equivalent function of Group Sustainability Affairs at the time, there was significant support from environmental specialists. Another difference was that the head of that function was an active supporter of the project and environmental initiatives in general (PC, 2008r), acting as an influential environmental champion. And finally the ecodesign training of employees is assumed to be significant as the project commenced within 5 years of the end of the training programme. Due to the significant length of time since the initiation of the project, interviews were unable to determine if cross-functional teams were used in the development.

6.5.4 Barriers and Reasons for Failure

While the rationale is clear and the practice is common for businesses to purchase only the function of equipment instead of buying it outright, consumers don't see it as so obvious. Consumers are used to owning their own machines and are unaware of the actual cost of operation due to it being hidden in the electricity and water bill, and the grocery bill for detergents. When people share washing machines in Sweden the operating cost is included in the rent as a flat rate, hiding the cost further. Consumers were surprised by what they misinterpreted to be a high cost of washing in the Functional Sales system (PC, 2008r).

The ideal consumers for a system such as this were seen to be younger segments not looking to commit to owning a washing machine and open to the concept of 'renting' one. The system would also work best in an urban area giving access to a larger potential market and facilitating economies of scale in servicing and installation. While Gotland was one of the few places at the time providing a large set of homes with smart meters installed, the area did could not offer an ideal market, being a rural area without many young people. This is considered to be another barrier to the project's success (PC, 2008r).

The organisational model was also seen as a barrier in its unfamiliarity with the concept of service provision. No company pushing products out the door for nearly a century can switch to services overnight, but this was further hampered by inadequate communication and understanding across all relevant functions as to the goals and potential of the project (PC, 2008r). It should be taken into account that the project's status as an experiment may not have helped its recognition among other functions in the organisation and had the project been implemented on a larger scale, the communication and commitment may have been stronger.

With the state of the economy in 2000 bringing margins in the industry even lower, Functional Sales came under scrutiny and was discontinued (PC, 2008r). Although the experiment was not a commercial success nor proved the concept, it received significant positive attention in the media and for years afterward from academics (PC, 2008v).

7 Analysis

This section first meets the two research objectives by classifying the Product Cases as incremental and radical eco-innovation outcomes, and identifying differences in variables between their eco-innovation processes. Then the two objectives are synthesised and the observed results are compared with the anticipated results from the literature before the research question is answered.

7.1 Meeting the Research Objectives

7.1.1 Objective 1: Categorising Cases as Eco-Innovation Outcomes

Objective 1 aims to categorise the five Product Cases into degrees of incremental or radical eco-innovation outcomes (the independent variable) using Ehrenfeld's table below. Symbols have been added to Ehrenfeld's text in the table to aid reading. Significant is represented by ●, Minor by **O**, None to Minor by ○ and None by (   ). The grey areas are those parts added to the original table. As explained in the literature review (Section 3.1.2), Category 1 is an incremental eco-innovation and Categories 2, 3 and 4 are degrees of radical eco-innovation.

Category	Case	Change in Device Concept	Change in Infrastructure	Change in User Learning
1. Process and "Product" Redesign		○ None to minor	None	None
	A+ Washer	None	None	None
	Heat Pump	**O** Minor	None	None
	Sunny	None	**O** Minor	**O** Minor
2. Functional Innovation		● Significant	○ None to minor	None
	Iron Aid	● Significant	None	**O** Minor
3. Institutional Innovation		○ None to minor	● Significant	● Significant
	PSS	None	● Significant	● Significant
4. System Innovation		● Significant	● Significant	● Significant

Table 7-1 Analysis: Eco-innovation Outcomes

The A+ washer is firmly in the first category. As the machine is an entirely incremental improvement on an established typology there is no change in the device concept, infrastructure or user learning.

The Heat Pump dryer shows what is considered as a minor change in device concept through the addition of heat pump technology, but no change in infrastructure or user learning, putting it too in the first category. It could be debated that the addition of heat pump technology to a dryer is radical in terms of technology, energy efficiency and adaptation of the production process. While incremental improvements of established typologies – as observed in the A+ Washer case – have lead to a plateau in energy efficiency improvements, the heat pump has effectively ushered in a new curve in efficiency gains (see Figure 12-2 in Appendix). However, this paper argues that it is only a minor change in device concept, because although the technology is different, the product it still provides the same function in essentially the same manner and cannot therefore be a functional innovation. An example of a functionally radical dryer would be one that addresses the consumer need in a different way, such as a waterless washing machine which eliminates the need to dry clothes. Soil and odour resistant fabrics are perhaps the most radical eco-innovation in this context, as they could eliminate the need to clean clothing in the first place. To explore the categorisation further, it could be applied to automobiles.

The Hybrid Petrol-Electric Vehicle (HEPV) for example, would be categorised as incremental as it provides the same function in the same way as non-hybrid cars, but with arguably radical technology under the hood. A fully electric car requiring changes in infrastructure and user learning could be categorised as a system innovation.

This is an issue in using the clear framework of Ehrenfeld that was chosen for this study. Both the entirely incremental A+ washer and the arguably semi-radical Heat Pump dryer are both grouped in Category 1. However, the potential for heat pumps and further technological improvements in washing machines and dryers in their current typology is not regarded as high, and the next jump in efficiency is likely to come from a more radical eco-innovation where greater potentials lie.

The Sunny washer exhibits an insignificant change in device concept (a dual input), a minor change in infrastructure (a roof-mounted solar water heater), and a minor change in user learning as users must wash when solar heated water is available in order to reap the environmental and cost-saving benefits of the product. While the Sunny's minor changes in infrastructure and user learning mean it doesn't fit perfectly into the first category, it is still far from the second and third categories, which require significant changes.

The Iron Aid case shows a significant change in device concept when replacing a washing machine with its freshening feature, and when replacing an iron and ironing board, or trips to use the service of a professional dry cleaner. There is no change in infrastructure, but a minor change in user learning as the user must turn to a different device when making their clothing fresh and wrinkle-free. Apart from the minor change in user learning, the Iron Aid fits well within the second category of functional innovation.

The final case, Functional Sales or PSS, comes under the third category of institutional innovation with essentially no change in device concept, but significant changes in infrastructure and user learning.

The first three Product Cases are considered incremental eco-innovation outcomes, while the fourth (Iron Aid) is functionally radical, and the fifth (PSS) is institutionally radical. None of the cases fit into the fourth category of system innovation, which requires significant change in device, infrastructure and learning. In further discussion the fourth category is omitted from Ehrenfeld's table. The three categories of eco-innovation fulfilled by the Product Cases in the table above will be referred to as:

- Incremental (Category 1, Process and "Product" Redesign),
- Functionally Radical (Category 2. Functional Innovation) and
- Institutionally Radical (Category 3. Institutional Innovation).

7.1.2 Objective 2: Differences in Eco-Innovation as a Process

Objective 2 identifies differences in the eco-innovation processes. Before analysing the Product Cases individually, a diagram depicting the typical interaction of the first three dependent variables – drivers, procedures (represented by typical environmental information flows) and functions – is presented. This diagram is based on the information gathered in the Base Case and does not include the fourth variable – success factors, which is too specific to be mapped in this way. The diagram is presented below with explanations following.

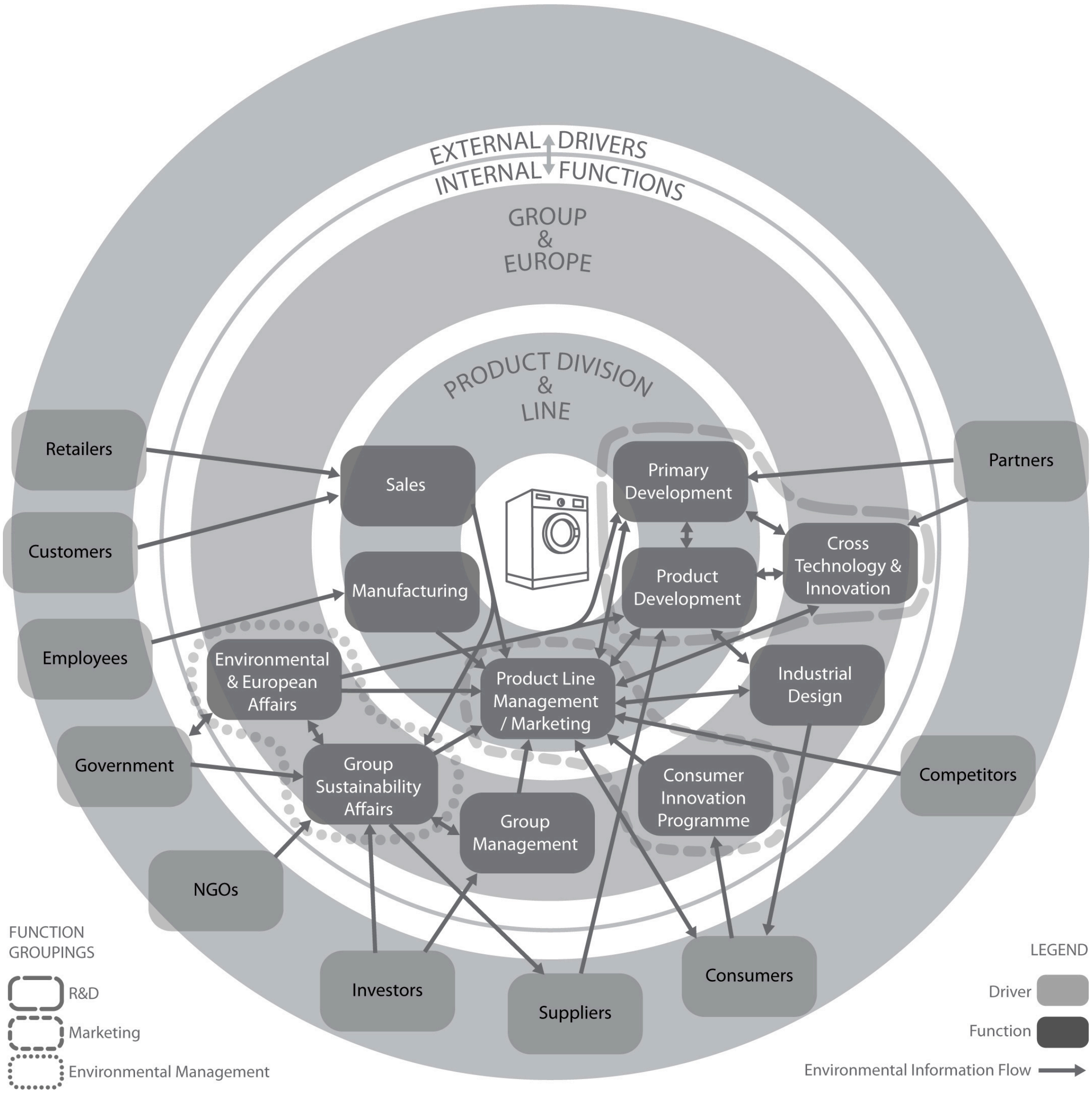

Figure 7-1 Base Case Map

The diagram is split into three circles, with the outermost representing drivers, and the two inner circles representing functions. The larger of the inner circles covers the Group and Europe level functions, while the innermost circle covers product division and line level functions. Generally the closer a function is to the middle of the diagram the more involved it is in the product's development.

All drivers and functions identified in the Base Case are depicted as boxes, some of which are displayed in their function groupings. The arrows denote flows of environmental information representing the procedure in this diagram. A few examples are highlighted below to explain the diagram.

Taking the Consumers driver for example, it sits with other drivers on the outermost circle, and the arrows indicate that it receives environmental information from both Product Line Management and Marketing (as tips on how to use the appliance most efficiently) and Industrial Design (guidance as to the most efficient programme choice through the user interface). More arrows indicate that consumers also communicate environmental information to Product Line Management and Marketing and the Consumer Innovation Programme (CIP), both through market research and purchasing decisions.

To take a function as an example, Environmental and European Affairs sits in the Environmental Management grouping on the larger of the inner circles as it as a Europe level function, and the arrows indicate it receives environmental information from Government in the form of policy proposals and legislation, and from Group Sustainability Affairs as proposed corporate environmental policy. Environmental and European Affairs in turn communicates environmental information back to Government as lobbying, back to Group Sustainability Affairs as input on the direction of corporate environmental policy, and on to Product Line Management and Marketing, Product Development, Primary Development and Manufacturing as EU policy evaluations, the implementation of corporate environmental policy and as a source of environmental expertise on specific issues.

Using the above diagram as context, the analysis for Objective B moves to the Product Cases to summarise and schematically represent differences between their eco-innovation processes. The significant and minor drivers and functions are displayed on a dimmed and cropped version of the Base Case diagram. Typical environmental information flows (i.e. existing in the Base Case) are displayed when two drivers or functions involved in the Product Case interacted in a similar manner as in the Base Case. Atypical environmental information flows are depicted when drivers and functions interact in a dissimilar manner to the Base Case.

While not shown on the diagrams, the six success factors are also discussed for each case. To provide context, evidence of the success factors in the Base Case (from 2008) is explained first:

● Commitment from top management was significant

Ecodesign training provided to product development personnel was none

○ Existence of an environmental champion was minor

○ Access to environmental specialists was minor

● Cross-functional teams was significant

● A mindset prioritising environmental issues as business issues was significant

7.1.2.1 A+ Energy Rated Washing Machine

The Significant drivers in this case were Consumers and Competitors, while a minor driver was Retailers. The significant function was Product Line Management and Marketing, who were most involved at the beginning of the process in interpreting consumer demand and conducting competitor analyses to make the case for the development of an A+ energy rated washing machine. Sales played a minor role in communicating environmental information from Retailers on to Product Line Management and Marketing. The typical flows of environmental information are depicted from Consumers and Competition to Product Line Management and Marketing, and from Retailers to Sales to Product Line Management and Marketing. The success factors for this case did not differ from the Base Case.

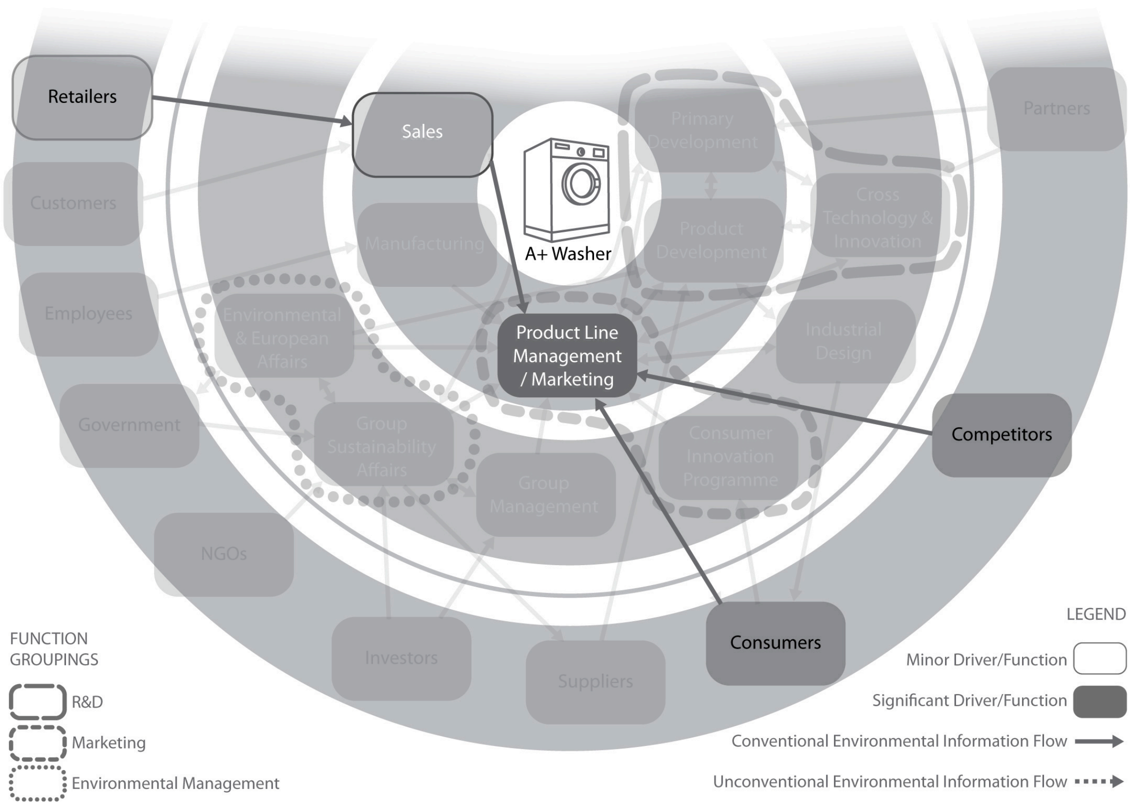

Figure 7-2 Product Case Map: A+ Energy Rated Washing Machine

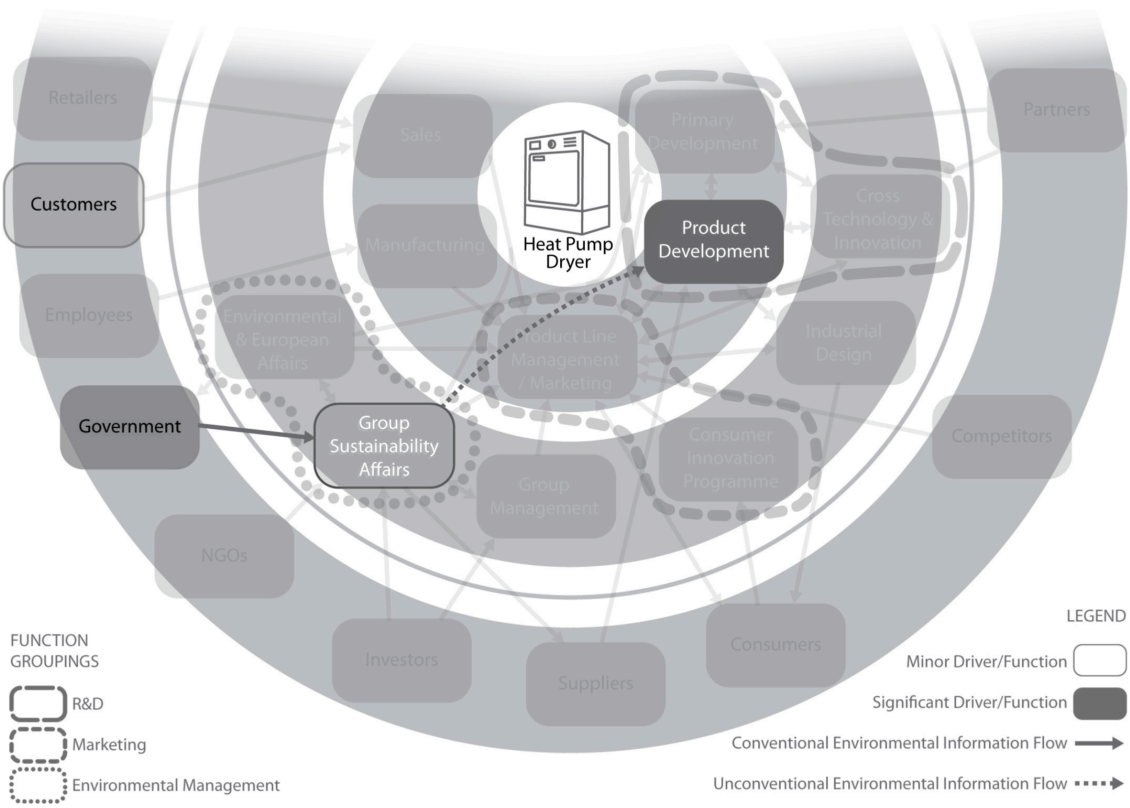

Figure 7-3 Product Case Map: Heat Pump Dryer

7.1.2.2 Heat Pump Dryer

Referring only to the initial innovation in 1996, the significant driver was Government, which was in turn influenced by the minor driver of Customers who guaranteed a market for the winner of the procurement programme. Product Development was the significant function, while Group Sustainability Affairs was a minor function in passing on the idea to enter the programme. While the flow of environmental information from Government to Group Sustainability Affairs was typical, Group Sustainability Affairs communicating product specifications to Product Development could be said to be atypical. No environmental information came from Customers as they had no direct communication with Electrolux. Ecodesign training, top management commitment and an environmental mindset were significant while the other success factors were unable to be determined.

7.1.2.3 Sunny Dual-Input Washing Machine

The significant driver in this case was Consumers in Italy, who were in turn influenced by the minor driver of Government through incentives towards solar heating installation. The significant function was Product Line Management and Marketing, who interpreted the strong demand from the market. The arrow in the diagram depicts the typical flow of environmental information from customer to Product Line Management and Marketing. The success factors identified for this case did not differ from the Base Case.

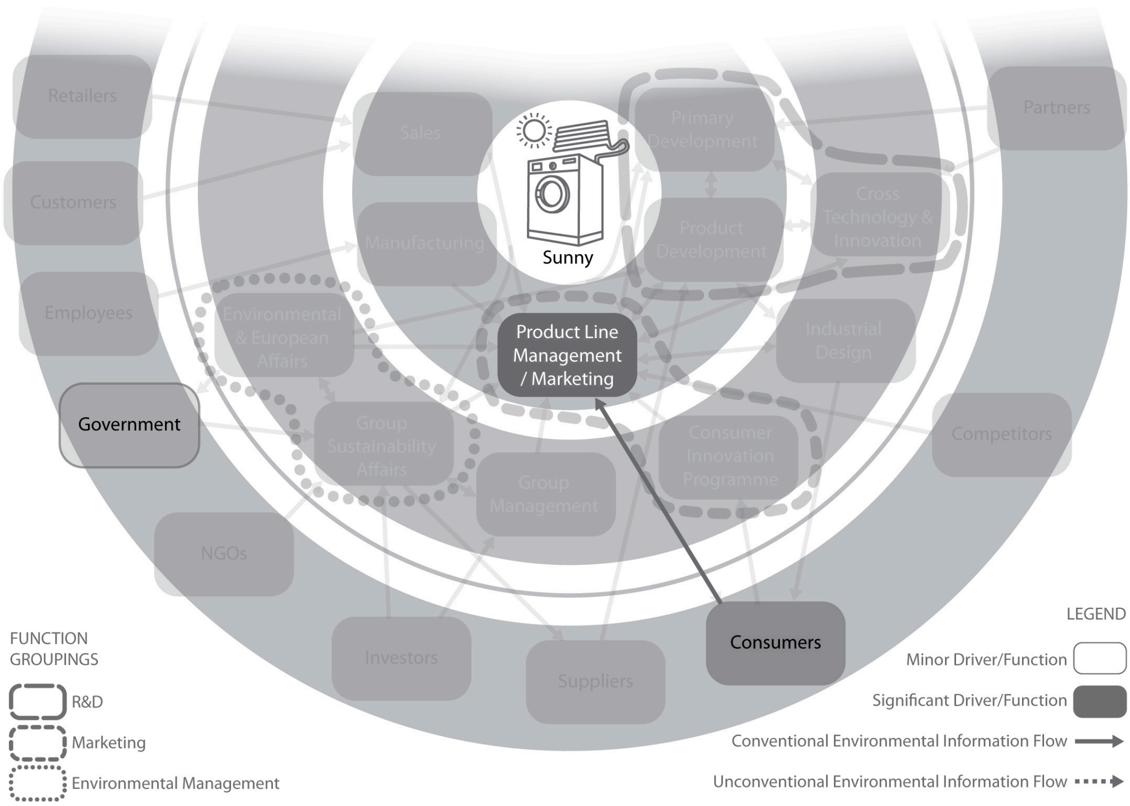

Figure 7-4 Product Case Map: Sunny Dual-Input Washing Machine

7.1.2.4 Iron Aid Steam Dryer

The concept began as an R&D project, meaning there was no significant external driver as it was an internal source of technology. Consumers were a minor driver in their desire to avoid manual ironing. Product Development was the significant function, and Product Line Management and Marketing was a minor function. This case involved typical flows of environmental information, and success factors did not differ from the Base Case.

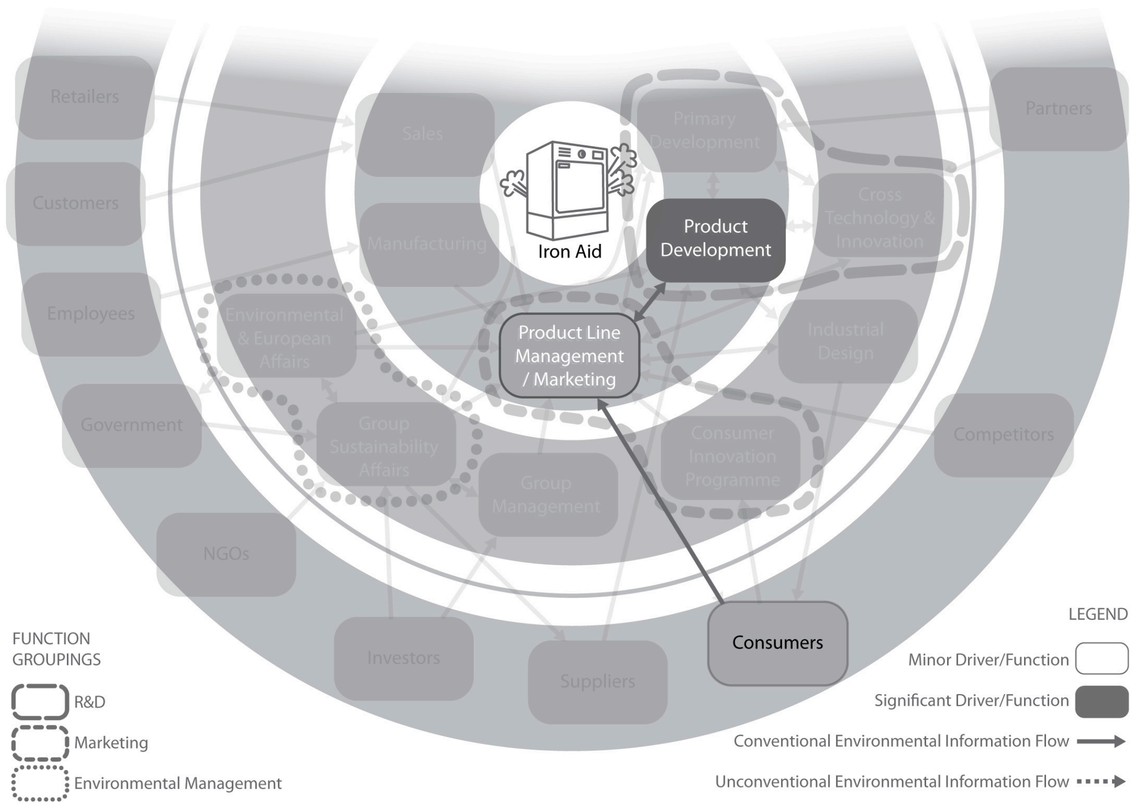

Figure 7-5 Product Case Map: Iron Aid Steam Dryer

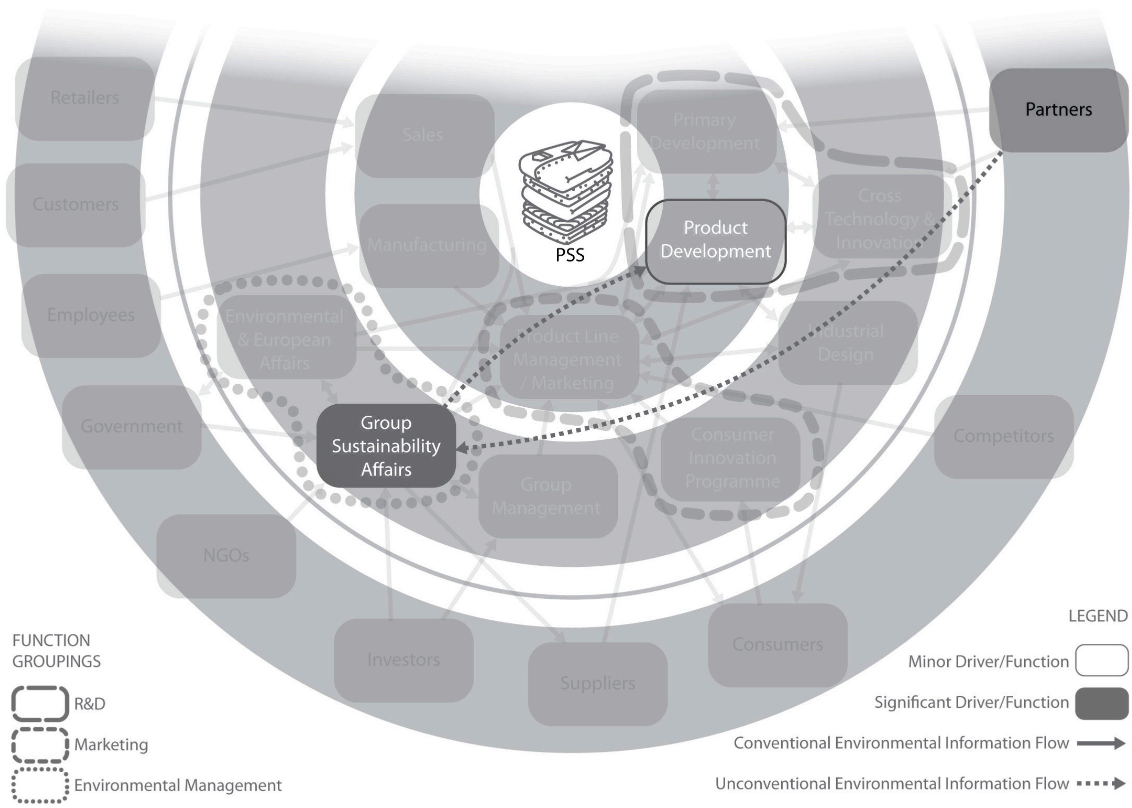

Figure 7-6 Product Case Map: Functional Sales PSS

7.1.2.5 Functional Sales PSS

The significant driver was a Partner – the energy company who had installed the smart meters. Group Sustainability Affairs was the significant function, and Product Development was a minor function. An atypical flow of environmental information went from Partners to Group Sustainability Affairs and on to Product Development. With regard to success factors, this case differed from the Base Case in having significant ecodesign training provided, significant existence of environmental champions, and significant access to environmental specialists.

7.2 Synthesising the Objectives

The results of Objectives 1 (incremental to radical classification) and 2 (significance of dependent variables) are combined in this section using matrices presented in the analytical framework.

7.2.1 Drivers

The significance of different drivers in each product case is plotted against the classification of cases from incremental to radical in the table below. As with the previous table (7-1), the symbols are Significant (●), Minor (○) and None ( ).

Category	Case	Consumers	Customers	Retailers	Competitors	Partners	Suppliers	Investors	Employees	Government	NGOs
1. Process and "Product" Redesign	A+ Washer	●		○	●						
	Heat Pump		○							●	
	Sunny	●								○	
2. Functional Innovation	Iron Aid	○									
3. Institutional Innovation	PSS					●					

Table 7-2 Analysis: Drivers

For the three incremental cases, drivers from the market were prevalent. Consumers were a significant driver in both the A+ Washer and Sunny, with Competitors also acting as a significant driver in the A+ Washer. The minor drivers of Retailers and Customers were evident in the A+ Washer and Heat Pump Dryer respectively. On the other hand, the Heat Pump dryer did not have a significant driver from the market but instead from Government, a driver also evident in the Sunny as one of minor importance. This points to the high importance of market and governance drivers in incremental eco-innovations.

For the functionally radical Iron Aid case, there was no significant driver under the definition used in this paper, which required drivers to exist outside the innovation process. However the technology developed in Product Development's laboratories was highly influential in spurring the innovation process, and would be considered a driver under other definitions used in the literature. Consumers were a minor driver in this case, as although they voiced their dislike of ironing and their positive impression of steam in the market analysis, they did not provide as strong an impetus to the initiation of the process as did technology.

For the institutionally radical PSS case, Partners were an important driver. The smart metering technology provided by Vattenfall was highly influential in driving the development of the eco-innovation. Electrolux would not have taken on the cost and risk of installing a base of smart meters themselves and therefore required a partner.

Customers, Employees, Investors, Suppliers and NGOs were not found to have influenced any of the cases. However, as noted in the Base Case, Customers and NGOs have elicited incremental eco-innovations at Electrolux before. The examples were the elimination of PVC for the Swedish market with Customers as the driver, and a change in refrigerant where the NGO Greenpeace was a driver.

The table is presented again below with the various drivers condensed into their groupings. When analysed by driver grouping it can be seen that the Market (Consumers and Competitors) and Governance (Government) were important for the incremental cases, Technology – while not considered a driver – was influential in the functionally radical case, and Industry (Partners) was influential for the institutionally radical case.

Category	Case	Market	Industry	Governance
1. Process and "Product" Redesign	A+ Washer	● Significant		
	Heat Pump	○ Minor		● Significant
	Sunny	● Significant		○ Minor
2. Functional Innovation	Iron Aid	○ Minor		
3. Institutional Innovation	PSS		● Significant	

Table 7-3 Analysis: Driver Groupings

7.2.2 Procedures

The significance in change in procedure for each product case is plotted in the table below.

Category	Case	Change in Procedure
1. Process and "Product" Redesign	A+ Washer Heat Pump Sunny	○ Minor
2. Functional Innovation	Iron Aid	
3. Institutional Innovation	PSS	● Significant

Table 7-4 Analysis: Procedures

The extent to which the innovation processes of the Product Cases differed from the typical procedure was difficult to assess accurately. For this reason two methods were used to determine this variable for each product case. One was to compare the observed process to the Product Management Flow procedure, and the other was to compare the flows of environmental information in the Product Cases to the typical environmental information flows identified in the Base Case. If a case differed from the typical procedure and from the typical flows of environmental information it is considered to have a significant change in procedure. If it differed in only one method it is considered to have minor change in procedure.

For the first method it was only possible to accurately discern deviation from the PMF procedure in the institutionally radical PSS case. There the innovation process did not go through core stages in the PMF procedure as usual. Using the second method, the incremental Heat Pump dryer case exhibited one atypical flow of environmental information, while the PSS case exhibited two such atypical flows of environmental information and no typical flows. The Heat Pump case therefore has a minor change in procedure while the PSS case has a significant change. All other cases did not exhibit any change in procedure. Interestingly, the institutionally radical case showed a significant change, while no change in procedure was observed in the functionally radical case.

7.2.3 Functions

The significance of different functions in each product case is plotted against the classification of cases from incremental to radical in the table below.

Category	Case	Product Line Mgmt & Marketing	Consumer Innov-ation Programme	Product Development	Primary Development	Core Technology & Innovation	Group Sustainability Affairs	Environmental & European Affairs	Industrial Design	Group Management	Manufacturing	Sales
1. Process and "Product" Redesign	A+ Washer	●										○
	Heat Pump			●			○					
	Sunny	●										
2. Functional Innovation	Iron Aid	○		●								
3. Institutional Innovation	PSS			○			●					

Table 7-5 Analysis: Functions

In the three incremental cases, Product Line Management and Marketing was the significant function for the Sunny and A+ washer, with sales having a minor role in the A+ case. For the Heat Pump dryer Product Development was the most involved function in developing the technology, while Group Sustainability Affairs had a minor role.

For the functionally radical Iron Aid case, Product Development was the most involved in the early stages, developing the technology for steam generation in the dryer. Product Line Management and Marketing had minor involvement through market research and consumer verification.

For the institutionally radical PSS case, Group Sustainability Affairs was the most involved function in initiating the innovation process. It worked with the Partners to help arrange the system and involved Product Development as a minor function in adapting the machines to allow the washing cycles to be measured by Vattenfall's smart meters.

It is important to note why certain functions have featured frequently in the Product Cases while functions with similar roles have not. This can be seen in the table above where all instances of involvement from the R&D grouping are from Product Development, and all instances of the Environmental Management grouping are Group Sustainability Affairs. The lack of Core Technology and Innovation's involvement in the Product Cases is due to the fact that that function did not focus on innovation until recently, after the development of these cases. Primary Development has been working on product innovations for a long time and was involved in many of the cases in supporting roles, but due to its small size in comparison to Product Development's research laboratories it has not been the 'source' of any of the case eco-innovations. The fact Environmental and European Affairs was not involved in any of the cases is because it was formed relatively recently. The two cases in which its counterpart Group Sustainability Affairs was involved (the Heat Pump dryer and the PSS) actually took place before Environmental and European Affairs existed. At that time both functions were contained in a single group-level environmental management function, which became Group Sustainability Affairs when Environmental and European Affairs was formed. Therefore, for discussions of the involvement of different functions it is perhaps more relevant to the current situation to talk of the groupings R&D and Environmental Management.

The table is presented again below with the various functions condensed into their groupings. When analysed by function grouping it can be observed that Marketing was most influential in the incremental cases, R&D was most influential in the functionally radical case but also in one of the incremental cases and Environmental Management was most influential in the institutionally radical case.

Category	Case	Marketing	R&D	Environmental Management	Other
1. Process and "Product" Redesign	A+ Washer	● Significant			○ Minor
	Heat Pump		● Significant	○ Minor	
	Sunny	● Significant			
2. Functional Innovation	Iron Aid	○ Minor	● Significant		
3. Institutional Innovation	PSS		○ Minor	● Significant	

Table 7-6 Analysis: Function Groupings

7.2.4 Success Factors

The occurrence of different success factors in each product case is plotted against the classification of cases from incremental to radical in the table below.

Category	Case	Top Mgmt Commitment	Ecodesign Training	Environmental Champions	Access to Specialists	Cross-functional Teams	Environmental Mindset
1. Process and "Product" Redesign	A+ Washer	●		○	○	●	●
	Heat Pump	●	●	n/a	n/a	n/a	●
	Sunny	●		○	○	●	●
2. Functional Innovation	Iron Aid	●	○	○	○	●	●
3. Institutional Innovation	PSS	●	●	●	●	n/a	●
	Base Case	●		○	○	●	●

Table 7-7 Analysis: Success Factors

It can be seen in the table above that for half of the success factors there was no change from case to case. As explained in Section 4.1.2.4, this is because some of the factors – notably top management commitment, cross-functional teams and environmental mindset – are relatively long term and did not change between the short durations of the cases. Any case occurring after the introduction of the PMF and following that procedure will have used cross-functional teams for example.

In ecodesign training, environmental champions, and access to environmental specialists however, there were some differences between cases.

For ecodesign training it was assumed that due to the Heat Pump and PSS cases occurring within 5 years of the ecodesign training programme, and the Iron Aid within 10 years, the programme would have had influence on those involved in the case. Due to the limitations of this assumption it is perhaps best to only garner the possibility that the institutionally radical PSS case had been positively influenced by the recent training programme.

The PSS case is the only case to have significant environmental champions and access to environmental specialists. This was due to the high involvement of Group Sustainability Affairs in the innovation process. While far from certain, it could be reasoned that the increased environmental expertise and motivation on hand during development had a positive effect on the initiation of the institutionally radical PSS case.

To summarise the differences in success factors, the institutionally radical PSS case exhibited training, champions and specialists, while the functionally radical and incremental cases generally had less training, champions and specialists.

The success factors variable did not yield significant differences among cases as were seen in the previous three variables. While further differences likely existed at the time of development, these were perhaps overlooked in data collection due the broad and generic nature of the selected success factors. Taking top management support as an example, the literature essentially defines this as a success factor for ecodesign due to the improbability of ecodesign under management with no interest in such initiatives. Top management at Electrolux has been continuously interested in environmental initiatives since a time before the earliest of the chosen cases began, and therefore all cases showed significant top management commitment. However, with a different interpretation of top management support, e.g. that top management must have explicitly backed a certain development project, different results may have ensued. The development of the A+ Washer for example did not have such explicit top management support as it was a very typical innovation, while the PSS case did.

7.3 Anticipated and Observed results

The results of the analysis are compared with the summary of the literature in the table below, which shows significant correlation between the anticipated and observed differences in variables. As mentioned in the literature review, the anticipated results are based on New Product Development literature that does not differentiate between levels of radical innovation in the same way as the eco-innovation field does. The radical row in observed results has been split into two to represent the two types of radical innovation dealt with in the analysis; functional innovation and institutional innovation. The 'incremental' and 'functionally radical' categories in the observed results can be compared directly with 'incremental' and 'radical' in the anticipated results, however the 'institutionally radical' category was expected to differ from the anticipated results for 'radical'. No anticipated results were made for the fourth variable, success factors, as this variable was analysed using a more inductive approach. The results of this variable are included in the table to allow comparison of the observed results across all variables.

	Drivers	Procedures	Functions	Success Factors
Anticipated Incremental	Market	Typical	Marketing	n/a
Observed Incremental	Market, Governance	Typical	Marketing	Minor Training, Champions & Specialists
Anticipated Radical	Technology	Atypical	R&D	n/a
Observed Functionally radical	(Technology)	Typical	R&D	Minor Training, Champions & Specialists
Observed Institutionally Radical	Industry	Atypical	Environmental Management	Significant Training, Champions & Specialists

Table 7-8 Anticipated and Observed Results

For incremental eco-innovation the observed results mirrored the anticipated results with one addition, which was that of governance as a driver. This ties in well with the discussion in Section 3.3.1 in the literature review, which explains the additional driver of Government for eco-innovation because of the public good it provides. Governance is a driver for incremental and not radical eco-innovation because Government typically bases legislation and other measures on products currently in the market, focussing on incremental improvements and not radical changes. This is discussed further in Section 8.3.2.

The observed results for the functionally radical case fit with the anticipated results well for the variables of drivers and functions, but the procedure variable differs from the anticipated result. While an atypical process was expected, the case study did not find strong evidence of a divergence from the Product Management Flow or typical flows of environmental information. The process did however begin within R&D, instead of Marketing as is typical, but this alone did not warrant the classification of the Iron Aid case as having deviated from the prescribed procedure. Although it was not a driver used in the analysis, technology is used in the table as the driver for the functionally radical case in parentheses. Technology has been used because there was no other significant driver, technology was noted in the interviews as being influential, and technology is used as a driver in the literature on which the anticipated results are based.

The observed results for the institutionally radical case are not covered directly by the anticipated results, but when compared to the results anticipated for the functionally radical case they show a similarity in not following typical procedures. The drivers for the institutionally radical case differ from the functionally radical drivers in the importance of Partners in the Industry grouping. The functions in the institutionally radical case also differed from the functionally radical case in the importance of Environmental Management instead of R&D.

7.4 Answering the Research Question

The research question is revisited below:

> "*What are key differences in the process of achieving incremental and radical eco-innovations?*"

Four sub-questions were developed to answer the main research question, and these are answered below:

i. *"Why does Electrolux pursue incremental and radical eco-innovations?"*

The case studies found that incremental eco-innovations were pursued because of the Market (market-pull) and Governance (regulatory-push/pull), while functionally radical eco-innovations were pursued because of technology (technology-push). Institutionally radical eco-innovations were pursued due to collaboration with Partners.

ii. "*How does Electrolux manage incremental and radical eco-innovations?*"

It was found that incremental and functionally radical eco-innovations generally conformed to the procedure used to manage the innovation process within the company, while institutionally radical eco-innovations were achieved through an atypical process deviating from the procedure.

iii. "*Who in Electrolux is involved in achieving incremental and radical eco-innovations?*""

Marketing functions were most important in the early stages of incremental eco-innovations, R&D functions were most important in functionally radical eco-innovations, and Environmental Management functions were most important in institutionally radical eco-innovations.

iv. "*Which of the success factors suggested in the literature are evident when Electrolux achieves incremental and radical eco-innovations?*"

While the literature does not suggest success factors specific to incremental or radical eco-innovation, the case studies found more ecodesign training for employees, a greater involvement of environmental champions and better access to environmental specialists in the institutionally radical eco-innovation case.

8 Discussion

8.1 Replacing Old Appliances

As touched on in the introduction, a barrier to the improved energy efficiency of the stock of washing machines in Europe is the low replacement rate of major appliances. This is due to the long average lifetime of 14 years (ISIS, 2007a) and the tendency for consumers to wait until an appliance breaks before replacing it even if it is highly inefficient (PC, 2008j). This has resulted in about 40 million washing machines in the EU that are over 10 years old and are far less efficient than those currently on the market (ISIS, 2007a).

As a consumer good, laundry appliances are inherently less appealing than the products of other industries such as automotive or consumer electronics. While many people pore over magazines about cars or electronic gadgets purely out of interest, and some camp outside stores to be the first to buy a new mobile phone, the same cannot be said for laundry appliances. Consumers replace mobile phones when they go out of style, but laundry appliances are used until they stop spinning. One respondent put it succinctly: *"People realise they have a washing machine only when it's broken"* (PC, 2008j). And after realising the existence of a broken washing machine in their house, the consumer must buy a new one in a matter of days. Unlike automotive sales people, those working in large retailers for major appliances are typically inexperienced and have little knowledge of the product (PC, 2008f). The purchase decision is often made in store in a short amount of time based limited information, leading to a poor choice considering the lasting economic and environmental costs associated with it (PC, 2008f).

The purchase cost of a washing machine typically accounts for less than 40% of the total economic cost to the consumer over the life of the machine, with the rest made up of electricity and water costs (Rüdenauer & Gensch, 2005). Refer to Figure 12-4 in the Appendix for a visual representation. Studies have shown that it is beneficial to the consumer in terms of economic cost to replace the machine earlier than its expected lifetime, and when considering the environmental costs to society from a lifecycle perspective, it is beneficial to replace the machine only a few years after purchase (Rüdenauer & Gensch, 2005). Taking the environmental benefits to society into account and the increased revenues to manufacturers, it is in the interest of both industry and government in increasing the rate of major appliance replacement. Electrolux and other manufacturers have pushed this issue hard through their industry organisation CECED, proposing government incentives that encourage replacement (Bygge, 2006).

Surveys by competitors have identified considerable willingness to replace appliances early in some European markets, where consumers in Germany (42%), Switzerland (34%), Belgium (30%) and the Netherlands (20%) answered that lower energy consumption is a reason for them to buy a new major domestic appliance, even if the old one still works (Whirlpool 2008b). Whether this actually happens can be debated, but it shows that certain markets may be turning towards faster replacement. It has been noted that the laundry room is receiving more spending by consumers (Yngen, 2006), however it cannot compete with the kitchen yet, where consumers are now known to replace all appliances once one breaks down to achieve a unified look (PC, 2008e).

However, for the most part consumers are unlikely to voluntarily replace working laundry appliances unless legislative incentives are introduced. Radical eco-innovation on the other hand, may have the potential to solve some of these issues, as outlined below.

8.2 The Business Case for Radical Eco-Innovation

Consumers buy washing machines in order to keep their clothing clean. If a new more energy efficient product offers exactly the same function at a lower total cost, the consumer is unlikely calculate the break even point and will not replace their old machine until it refuses to turn, as explained above. In other words, if new products fulfil the same function as the products they replace, they must wait 14 years between sales for the average consumer. If a product provides a different function, such as a functional eco-innovation, it may have a higher chance of displacing older products before they break down. This was noted by one interviewee in the case of the Iron Aid, which was replacing working dryers in consumers' homes by offering additional functionality (PC, 2008e). The same result was evident in the PSS case, where old appliances would be continuously replaced with the latest and most energy efficient models through servicing.

By addressing the function required by the user (clean clothing, or unwrinkled and fresh shirts) in a different way, radical eco-innovation has the potential to increase the slow replacement rate of laundry appliances, achieving environmental benefits and increasing revenue for the manufacturer.

8.3 Barriers to Radical Eco-Innovation

This section covers selected barriers which could hamper the development of radical eco-innovations – essentially reasons why laundry rooms might not look like the one described in Section 5.2.2.3 in the immediate future. While various barriers exist, two central barriers emerged in the interviews and are considered by the author to merit further discussion. These were the organisation and government.

8.3.1 Organisation

The literature has already covered the trouble large organisations have with radical innovation (see Christensen, 1997). This is especially true for manufacturers like Electrolux in industries with low margins. These conditions mean that large firms must be very efficient in the way they develop and manufacture products in order to keep costs down and stay in the market. Economies of scale are important, and with each new product comes the fixed costs of everything from market verification to tooling for manufacture to quality control. For these reasons it is difficult to propose a production run of anything less than 10 000 units (PC, 2008q). Radical innovations often involve uncertainties, which preclude the option of large manufacturing runs. The PSS case for example, was carried out on a very small scale, and if it had required a significantly different product (which it did not), it would have struggled to secure to a large manufacturing order. The Heat Pump dryer, while not classified as a radical case in this study, was initially produced in numbers too small to warrant the fixed costs of manufacture and instead was handmade at very high costs. If an innovation does not fit within the streamlined procedure, it will be much harder to get to market (PC, 2008q).

According to an interviewee from Marketing, the PMF procedure used to manage the innovation process at Electrolux has been successful in taking out the uncertainty and risk involved in the early stages of the process, making innovation more systematic and directed towards consumer needs, as opposed to R&D developing innovations without an eye on the market (PC, 2008t). While this may work in most cases, in others it may stifle potentially radical eco-innovations for which a market application is not immediately obvious or possible to verify. In the PSS case, its atypical development process was cited a barrier to its success.

Due to these barriers, it was the opinion of an interviewee from R&D that although ideas are plentiful, the truly radical innovations will not see the market through Electrolux and must be pursued with the support of Partners or Original Equipment Manufacture (OEM) (PC, 2008e). This was an important aspect in the PSS case, where the energy company Vattenfall was the most influential driver in having a network of smart meters set up already, something Electrolux would not have done themselves.

8.3.2 Government

While legislation and other initiatives by government can be useful in bringing about incremental eco-innovation and highly effective in diffusing eco-innovations, these measures are generally less effective in eliciting radical eco-innovation. This is not to say that measures by governments are entirely ineffective in encouraging radical eco-innovation – literature has covered the topic (see Ashford, 1999) and there are examples of legislation stimulating eco-innovation in the past that could be considered radical (such as the Zero Emission Vehicle regulations in California). However, measures by governments invariably aim to guide manufacturers in a more socially desirable direction, not to put half the industry out of business, as a radical innovation might (e.g. word processors and typewriters). Legislation in the EU is set in consultation with industry, and unless the majority of manufacturers had already adopted a particular radical eco-innovation they would be unlikely to let legislation mandate it. The influence of industry is greater still when sectors set voluntary or semi-voluntary standards. Even when EU legislation requires significant adaptation by manufacturers, such as the RoHS directive for example, having to replace lead solder in appliances as Electrolux did is unlikely to spur a radical eco-innovation.

Other forms of legislation offer carrots instead of sticks, such as procurement programmes or the EU energy label. A procurement programme was a key driver in developing the Heat Pump dryer, which although not categorised as radical in this study, had radical elements to it and would have been unlikely to have come from the type of legislation mentioned above. By encouraging beyond-compliance innovation, these legislative measures have potential to incite radical innovation. However they are limited in that they are still based on prevalent ideas about how to fulfil functions. Even the competition for the Heat Pump dryer asked for a device to dry clothing, not dry clothes. Therefore a truly radical innovation, such as a waterless washing machine that negates the need for a dryer or a very stylish clothesline would not be able to win the competition.

The problem is further accentuated in the EU energy-labelling scheme. Of the five Product Cases, not one was accurately rated by the system. The A+ washer and Heat Pump dryer went beyond the scale, while the main environmental features of the Sunny, Iron Aid and PSS cases were not recognised in the label criteria. The energy label is based on criteria that may not accurately reflect the functional requirements of the user. For washing machines the swatches represent the toughest stains around, yet the 'dirtiest' clothing of most consumers only requires the B washing rating (PC, 2008i), and the great majority of clothing washed is not actually dirty but just carries odours or wrinkles (PC, 2008f). In the case of the Iron Aid, it scored badly as a dryer in the scheme because of the small efficiency losses in providing the additional substitutive functions, which make it a far more efficient product than a B-rated dryer and an iron – its functional equivalent when de-wrinkling. In the Iron Aid case the labelling scheme not only failed to encourage its development through not recognising its environmental benefits, but in fact discouraged it through the low energy rating.

The legislation relevant in these cases may have been effective in promoting some incremental eco-innovation, but was ineffective in promoting radical eco-innovation. Other examples of legislation not covered by this study may have greater potential in encouraging radical eco-innovation, but are beyond the scope and would be a topic for further research.

9 Conclusions and Recommendations

This paper looked at the development of five Product Cases at Electrolux and attempted to distinguish differences in the processes leading to incremental and radical eco-innovations. The cases were few and diverse enough to preclude the development of truly generalisable characteristics for incremental and radical eco-innovation processes. However a number of observations were made from the cases that supported the findings of previous studies in the literature, and provided insights in areas where literature was not found.

The key observations were that for the three eco-innovations categorized as incremental, either Consumers or Government were the main driver in the innovation's initiation. The incremental cases also exhibited a greater involvement of the Marketing functions early in the process, while R&D was involved earliest in one of the three cases. The development process of the incremental eco-innovations tended to follow the procedure used to manage product development at Electrolux.

The functionally radical eco-innovation did not exhibit a strong external driver, and technology was instead considered to be an internal driver in that case. The development process appeared to conform to the Electrolux procedure and R&D was determined to be the most involved function early in the process. The institutionally radical eco-innovation showed Partners as the strong driver, and its development process differed significantly from the typical procedure. Environmental Management was the most involved function, and a number of success factors from the literature were identified in this case and not to the same extent in the others. These success factors were environmental education, environmental champions, and access to environmental specialists.

Important barriers to radical eco-innovation were identified in the way that both legislation and Electrolux as an organisation are geared towards incremental not radical innovations.

Based on the observations and insights gained through the analysis, four recommendations are proposed to encourage radical eco-innovation in Electrolux.

Greater Integration of Environmental Management in the Innovation Process

Environmental Management is the organisation's key source of environmental expertise and is integrated in the innovation process in order to reduce potential environmental impacts. However, as noted in the Base Case this is usually in the later stages in the process where the product concept is well defined or perhaps already specified, meaning most aspects of the product can no longer be changed. Integration at this stage inevitably leads to a reactive role by Environmental Management and a negative perception of the function's involvement. Product concepts late in the process already have significant time invested in them, and environmental considerations jeopardising their progress can understandably lead to friction between functions. The earlier environmental considerations are included in the innovation process, the greater the potential for improvement in environmental performance, and the earlier the involvement of Environmental Management, the less environmental considerations contradict with concepts carrying sunk costs. Earlier involvement therefore facilitates a more positive engagement of Environmental Management, where environmental considerations can be perceived as an opportunity and not a cost. It was seen in the institutionally radical case that the integration of the Environmental Management function was very early in the process. This allowed more access to environmental specialists and environmental champions, which are identified as ecodesign success factors in the literature.

The early and positive contribution of Environmental Management is currently rare at Electrolux, with limited involvement in the strategic matters of the Green Range, and no contribution to other projects such as the Cross Technology and Innovation initiative looking into environmental innovation. Inclusion of staff from Environmental Management in these projects in the early stages could provide expertise and motivation towards eco-innovations, and could lead to greater effectiveness and efficiency in the pursuit of radical eco-innovations. Further benefits of such early integration could be a gradual change in perception of the Environmental Management function from reactive to proactive, which may eventually facilitate increased voluntary requests for involvement in other projects at different stages, potentially reducing the need for Environmental Management to involve itself unilaterally.

Reintroducing Environmental Education

Environmental education was strong a number of years ago when the institutionally radical case was initiated, but has since resided. While the mentality appears to live on in employees, new employees may not be able to gain a thorough understanding of the environmental implications and opportunities of their role in the organisation simply though on-the-job training. A formalised environmental module could be added to new-recruit training to ensure the environmental awareness in employees is sustained through employee turnover. Environmental education could take many forms, and could be provided to those already holding sound environmental awareness in a less formalised manner to freshen knowledge of the subject and provide inspiration. This study does not attempt to make concrete suggestions in this area, as the design of a second wave of environmental education would require another study altogether.

Freedom for R&D Functions

The freedom of R&D to develop concepts without the strong input of market information is recommended. This study did not assess the degree to which R&D was or was not free to develop at Electrolux and therefore does not recommend less or more freedom, but simply draws attention to the importance of giving R&D the flexibility to develop without having to prove market applicability too early. The procedure used to manage the innovation process attempts to limit the amount of development work not directed at topics identified by marketing as potentially interesting for the consumer. This may be detrimental to truly radical eco-innovations that do not have obvious market applications from the beginning or are verified poorly in market research due to consumers' unfamiliarity with the radically new innovation.

External Collaboration

As explained in Section 8.3.1 above, the organisation constitutes a significant barrier to radical eco-innovation, which can be circumvented through collaboration with partner organisations. A company such as Electrolux has the expertise and finances to pursue radical eco-innovations, but not the flexibility. Therefore it is important to collaborate as was seen in the institutionally radical case. Collaboration allows Electrolux to pursue a greater diversity of radical eco-innovations and in smaller scales.

9.1 Suggested Topics for Further Research

Several topics have arisen in this study that present interesting areas for further research with Electrolux. This paper took a strategic look at the process of radical eco-innovation, however a more operational perspective could be interesting, especially with regard to the recommendations. This could entail an operational assessment of how to integrate environmental management functions into the early stages of the process, how to initiate a second wave of environmental education, or how to facilitate external collaboration with Partners. Other potential topics could be the role of legislation in promoting radical eco-innovation, or the role of industrial design and user interfaces in influencing user behaviour.

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11 Abbreviations

CECED	(European Committee of Domestic Equipment Manufacturers)
CEO	Chief Executive Officer
CIP	Consumer Insight Program
CTI	Core Technology and Innovation
EuP	Energy using Products
EMS	Environmental Management System
EU	European Union
FMEA	Failure Mode and Effect Analysis
GWh	Gigawatt hour
IPDP	Integrated Product Development Process
ISO	International Organization for Standardisation
kWh/kg	kilowatt hour per kilogram
LCA	Life Cycle Assessment
NPD	New Product Development
NGO	Non Governmental Organisation
PVC	Polyvinyl Chloride
PCP	Product Creation Process
PMF	Product Management Flow
PSS	Product Service System
QFD	Quality Function Deployment
REACH	Registration, Evaluation and Authorisation of Chemicals
RML	Restricted Material List
RoHS	Restriction of Hazardous Substances
TRIZ	(Theory of Inventive Problem Solving)
WEEE	Waste Electrical and Electronic Equipment

12 Appendix

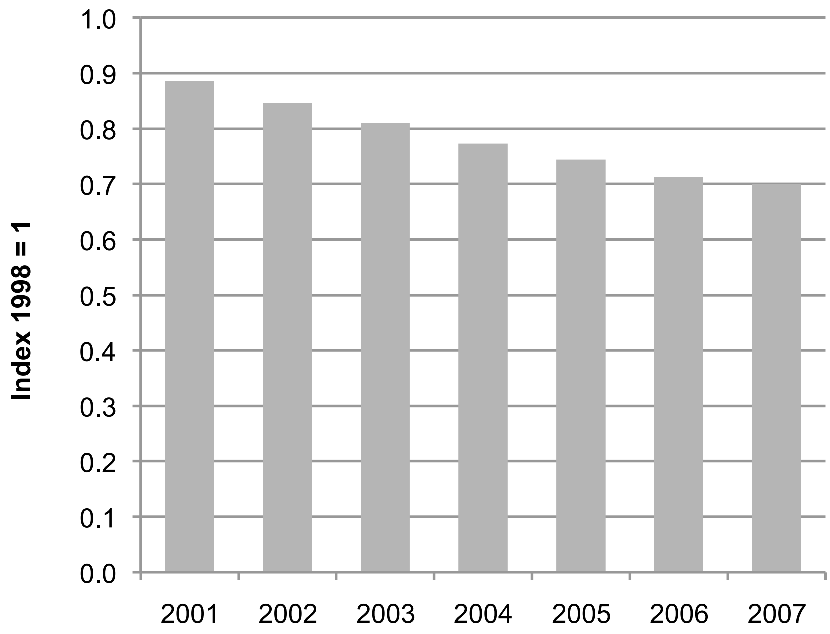

Figure 12-1 Electrolux Washing Machine Efficiency: Fleet Averages

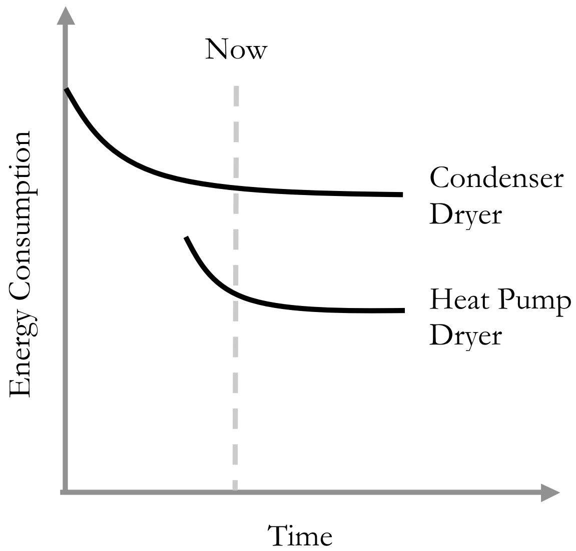

Figure 12-2 Conceptual Heat Pump Dryer Efficiency Curve

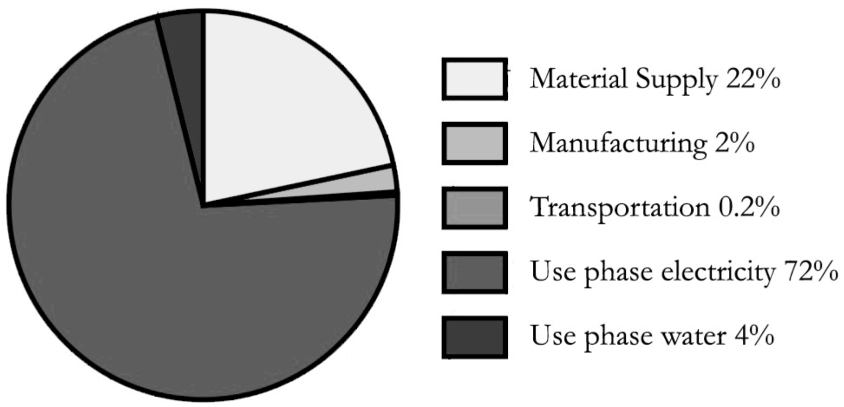

Figure 12-3 Life Cycle Assessment of a Washing Machine

Source: Rüdenauer et al., 2004

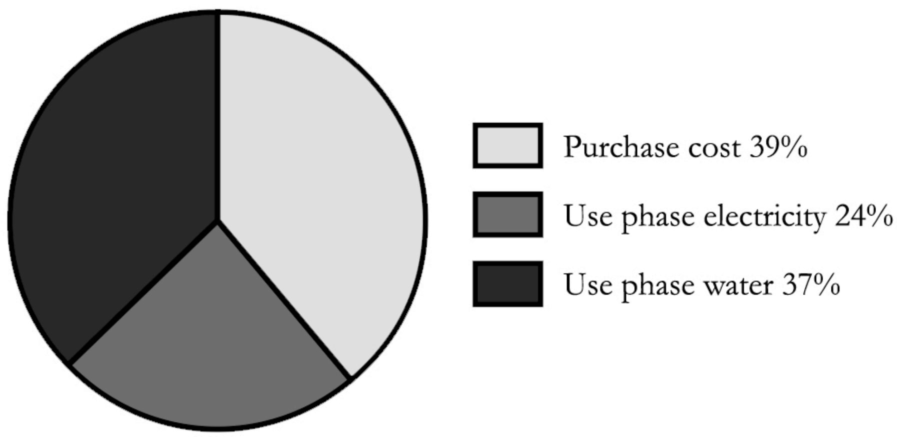

Figure 12-4 Life Cycle Cost of a Washing Machine

Source: Rüdenauer et al., 2004

Date	Type	Position	Function	Level	Duration
18/06/08	Phone	Product Business Director for Washing Machines	Product Line Management (PLM), Washing Machines	Division/ Line	25min
18/06/08	Phone	Environmental manager for Swedish Sales, Product Line Manager for Laundry Sweden	Swedish Sales	Division/ Line	15min
25/06/08	In Person	Vice President - Environmental and European Affairs	Environmental and European Affairs	Europe	35min
		Project Manager - Environmental and European Affairs	Environmental and European Affairs	Europe	+25min
25/06/08	In Person	Energy Coordinator	Environmental and European Affairs	Europe	20min
3/07/08	In Person	Environmental manager for Swedish Sales, Product Line Manager for Laundry Sweden	Swedish Sales	Division/ Line	65min
3/07/08	In Person	Program Director	Consumer Innovation Programme (CIP)	Group	90min
4/07/08	In Person	Director - Global Energy Policy Affairs	Group Sustainability Affairs	Group	100min
		Director - Environment	Group Sustainability Affairs	Group	
7/07/08	In Person	Plant Manager	Manufacturing, Fabric Care, Porcia	Division/ Line	40min
		Manager, Electrolux Manufacturing System	Manufacturing, Fabric Care, Porcia	Division/ Line	+30min
7/07/08	In Person	Product Development Manager, Front-Loading Washing Machines	Product Development, Washing Machines	Division/ Line	70min
7/07/08	In Person	Manager of Primary Development	Primary Development, Fabric Care	Division/ Line	65min
7/07/08	In Person	Product Business Director for Washing Machines	Product Line Management (PLM), Washing Machines	Division/ Line	40min
8/07/08	In Person	CTI Director	Core Technology and Innovation (CTI)	Group	115min
		Innovative Projects Manager	Core Technology and Innovation (CTI)	Group	
20/08/08	Phone	Environmental manager for Swedish Sales, Product Line Manager for Laundry Sweden	Swedish Sales	Division/ Line	30min
21/08/08	Phone	Program Director	Consumer Innovation Programme (CIP)	Group	40min
22/08/08	Phone	CTI Director	Core Technology and Innovation (CTI)	Group	40min
22/08/08	Phone	Manager of Primary Development	Primary Development, Fabric Care	Division/ Line	30min
25/08/08	Phone	Innovative Projects Manager	Core Technology and Innovation (CTI)	Group	20min
27/08/08	Phone	Project Manager	Electrolux Logistics	Europe	35min
27/08/08	Phone	Industrial Design Manager, Fabric Care	Industrial Design Centre, Porcia	Division/ Line	25min
28/08/08	Phone	Senior Industrial Designer, Dish Care	Industrial Design Centre, Stockholm	Division/ Line	25min
28/08/08	Phone	Product Marketing Director, Fabric Care	Product Line Management (PLM), Fabric Care	Division/ Line	50min

Table 12-1 List of Interviewees

A. Ecodesign Terms

Over the last decade or two there has been a steady proliferation of terms used to describe the incorporation of environmental aspects into product development. These include Ecodesign (Bhamra, 2004), EcoRedesign (Ryan, 1995), Green Design (Bhamra, 2004), Life Cycle Design (Keoleian & Menerey, 1994), Design for the Environment (DfE) (Sroufe et al., 2000; van Hemel, 1998), Design for Sustainability (DfS) (Bhamra & Lofthouse, 2007), Environmental New Product Development (ENPD) (Pujari et al., 2003), Environmentally Conscious Design (McAloone, 1998), Sustainable Design (Bhamra, 2004) and Sustainable Product Development (Diehl & Brezet, 2004) – to name but a few currently in circulation. The use of terms in the literature is seemingly arbitrarily and many are used interchangeably to refer to the same concept. Dewberry and Goggin (1996) attempt to differentiate between green design, ecodesign and sustainable design, saying that green design focuses on a single environmental issue, while ecodesign entails the reduction of the most pressing impacts during the product's lifecycle, and sustainable design assumes a holistic approach incorporating ethical concerns. Another attempt defines sustainable product development and DfS as the consideration of environmental, economic and social aspects, while ecodesign as the consideration of only environmental and economic aspects (Diehl & Brezet, 2004). In line with these two articles, this study uses the term 'ecodesign' to refer to the integration of environmental considerations in the product development process, an activity leading to eco-innovation.

B. Ecodesign Tools

Various tools have emerged to assist organisations in conducting ecodesign. These tools can be divided into those for analysis and those for improvement. Analysis tools assess the environmental impact of a product indicating where to focus ecodesign efforts, while improvement tools are those used by designers and engineers to assist in reducing impacts (McAloone, 2000). Analysis tools are more generic, while improvement tools are typically adapted in some way to the industry or company (Sweatman et al., 1997). Only a brief selection of tools are covered below, for a comprehensive review see Simon et al. (1998).

The central analytical tool is the Life Cycle Assessment (LCA), which is used to assess the environmental impact of a product throughout its entire lifecycle. If carried out thoroughly it can provide valuable information but can also be time-consuming. Although LCAs aim for objectivity, they can be manipulated by the practitioner. The systematic use of full LCAs in businesses is rare (Foster & Green, 2000) due to the time and money they consume (Ehrenfeld & Lenox, 1997). The investment required and amount of concrete information required by LCAs mean they are generally conducted later in the development process once specifications are set (Bhamra et al., 1999). Streamlined LCAs and tools based on LCAs or Life Cycle thinking often provide a more appealing route for businesses. An example is the LiDS (Lifecycle Design Strategies) Wheel, developed by van Hemel and Keldmann (1996), which does not quantify actual environmental impact but is useful for benchmarking a new product to ones already on the market.

Improvement tools include internally developed ecodesign handbooks and Restricted Material Lists (RML), and can also include the firm's Environmental Policy, Environmental Management System (EMS), and even the stage-gate product development process (Foster & Green, 2000). The three latter tools are highly specific to the organisation and widely used in industry, but are not specific to ecodesign. While they could have a significant influence on ecodesign, they are not commonly cited as ecodesign tools. Product-Orientated Environmental Management Systems (POEMS) are an attempt to systematically include ecodesign in an EMS (see Ammenberg & Sundin, 2005; van Berkel et al., 1999) but are not widely implemented.

Ecodesign tools in general encounter issues in achieving widespread adoption. A commonly cited problem is their complexity and the time required to learn and use them, resulting in their disuse when employees are faced the myriad of other demands placed on them (McAloone, 2000). It is widely acknowledged that the earlier in the process ecodesign activities take place the greater the effect (ISO, 2002), however, many tools are designed to be used after the design specification is set, when many of the important parameters are already determined (McAloone, 2000). Such tools are generally insufficient to bring about significant improvements in eco-efficiency (McAloone & Andreasen, 2004), and there is a noted scarcity of tools designed to be used earlier in the process in the pre-specification phase (McAloone, 2000). Analysis-based tools require details, which are simply not available at early stages in the process.

Ehrenfeld and Lenox (1997) found that ecodesign tools were often less effective than having environmental expertise on hand, pointing to the training of employees in conjunction with support from management as a more successful approach (also Lenox & Ehrenfeld, 1997).

C. Procedure Tools

Organisations commonly use tools to assist in product development. Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA) and the Theory of Inventive Problem Solving (TRIZ) are relevant examples of these tools that have potential applications in integrating environmental considerations into the development process.

QFD (Akao, 2004) is a methodology for applying consumer needs to technical parameters to identify and prioritise functional product requirements, design specifications and process specifications. It is widely used in various manufacturing industries (Perry & Bacon, 2007). In addition to needs of the consumer, other requirements on the product or process can theoretically be applied to QFD. Various authors have attempted to integrate environmental considerations into QFD (Zhang, 1999; Masui et al., 2003; Sakao, 2007), but documented examples of its practical application are scarce.

FMEA is tool for classifying, evaluating and managing risk, and is also widely used in manufacturing industries (Perry & Bacon, 2007). Typically employed later in the development process, FMEA is useful for addressing all kinds of uncertainties, including environmental risk.

TRIZ is a Russian acronym translated to English as 'Theory of Inventive Problem Solving' and is useful for resolving technical conflicts in innovation (ReVelle et al., 1998). Developed through the analysis of a vast number of registered patents, the methodology plots characteristics of technical systems against inventive principles, providing a source of inspiration to the practitioner. Integrating environmental considerations into product development frequently leads to technical conflicts, dematerialisation versus structural integrity and durability is a simple example. TRIZ therefore has potential to assist in eco-innovation, a topic that has been investigated in the literature (Low et al., 2000; Jones & Harrison, 2000) but with scarce documented utilisation in manufacturing firms.