Eindhoven University of Technology

MASTER

Green product categorisation
a redesign of the green product classification process

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Green Product Categorisation
A redesign of the Green Product classification process

Master Thesis
Green Product Categorisation
A redesign of the Green Products classification process

Master Thesis
E.A.M. van Amelsfort (0517818)

Eindhoven, 8-9-2008

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Royal Philips Electronics
Sector: Lighting
Location: Eindhoven
Department: Sustainability Team
Principal: Frank Altena
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Abstract
This project is executed with the goal to redesign Philips Lighting's current Green Product
classification process in such a way that it becomes more efficient and is able to classify large
amounts of products in a reasonable time. Six analyses on 30 case studies have led to five
hypothesized options for this redesign. A representative sample and an abnormality and sanity
tests (in case testing with the representative sample was not possible) resulted in four accepted
hypotheses (i.e. options for the simplification of the current process). These options have been
weighed against three criteria and the best option (estimating the comparable Life Cycle score
using the power relation with energy efficiency) is worked out in the redesign. Reflection shows
that the redesign has accomplished the goals set and has fulfilled most design requirements.
However, some limitations are found as well.
‘You can’t manage what you can’t measure’

Original source unknown
Management summary

Orientation
This report describes the results of a Master graduation project executed at Philips Lighting. The subject of the project is Lighting's Green Product classification process. The initial problem at Lighting mentions the existence of a gap between Philips' objective to have more Green Products and the used tools to classify products as such. Since this problem is very broad, Porras' Stream Analysis is used for the problem diagnosis. This analysis resulted in the identification of five root causes, two of which are out of reach for this project. Therefore, the problem definition for this project is: 'In the current Philips Lighting Green Focal Area Environmental Benchmark the guidelines regarding the input criteria (the quantitative composition of products) and the guidelines for the choice of reference products and are not clear and strong enough. Furthermore, a single database containing information on standard materials and amounts does not exist within Philips Lighting.' The project assignment, which is based on this problem definition, uses seven research questions as support and is defined as follows:

Redesign the process of the classification of Green Products. In order to do this, evaluate the current classification process, set requirements for the redesign of the process, explore options to adapt or replace the current process, and design options for an efficient tool to classify the whole Lighting product portfolio that make external verification possible.

The goal of the project is to redesign the Green product classification process in such a way that it complies with Philips' Brand Promise 'Sense and Simplicity'. It needs to become a more efficient process that is able to classify large amounts of products in a reasonable time.

Analysis current practices
Using desk research, literature and interviews, the current practices concerning the classification of Green Products have been analysed. These steps are in the scope of this project:

- The selection of reference product(s) to compare the candidate product,
- The Green Focal Area Environmental Benchmark to check the first requirement for becoming a Green Product (a Green Product must be 10% better in energy efficiency and at least equal hazardous substances or 10% better in hazardous substances and at least equal in energy efficiency),
- The Life Cycle approach (qualitative reasoning and Life Cycle Assessment (LCA)) to check the second requirement for becoming a Green Product (the Life Cycle score of a Green Product should be better than that of the reference product), and
- The third party review to validate the claims.

Philips' current practices include (internal, external and functional product) benchmarking and (detailed and screening) LCA as tools to measure performance. Studying literature led to the conclusion that the environmental indicators used in the benchmark should be SMART and that the Eco-Indicator 99 that Philips uses seems a suitable measure since it provides transparency in the weighting of environmental themes.

Analyses for redesign options
A case study sample of 30 updated lamps (including ballast if necessary) has been analysed. A centre of gravity analysis (calculating the contribution of the phases to the total Life Cycle score), an analysis of the Life Cycle scores (executing multiple linear regression and sensitivity
analyses), an analysis of the differences between Green Products and non Green Products for six characteristics (comparable Life Cycle score, energy efficiency, weight, weight per Lumenhour, hazardous substances, and hazardous substances per Lumenhour), a discriminant analysis (predicting the Green Product classification based on the scores for the parameters comparable Life Cycle score, energy efficiency, weight per Lumenhour, and hazardous substances), an analysis of the relation between the different parameters, and a comparison of the scores of technology-based clusters for the six characteristics resulted in five hypotheses:

- **H1**: The total Life Cycle score can be estimated using an add-up percentage to the use phase (based on results centre of gravity analysis).
- **H2**: The total Life Cycle score can be estimated using multiple linear regression, i.e. Equation 6-1 through Equation 6-6 (based on results sensitivity analysis).
- **H3**: Green Product classification can be estimated based on the discriminant function, i.e. Equation 6-7, using the parameters weight system/Lm*h, energy efficacy, mg mercury, and EI99/Lm*h (based on results analysis Green Products and no Green products and discriminant analysis).
- **H4**: The comparable life cycle score (EI99/Lm*h) can be estimated using the Power relation with energy efficacy, i.e. Equation 6-8 (based on results analysis parameters).
- **H5**: Green Product classification can be done using technology-based clusters (based on results analysis technology-based clusters).

These hypotheses have been tested by a sample that is representative for the whole product portfolio whenever possible. In case it was not possible, an abnormality test (comparing values estimated using the hypotheses with the actual values) and a sanity check (coupling estimated values back to detailed LCA results) have been executed. These tests have led to the rejection of hypothesis 3. Since they cannot be rejected hypotheses 1, 2, 4 and 5 have been considered options for the simplification of the Green Products classification process.

**Redesign**

Desk research, studying literature, and executing interviews have resulted in several design criteria. The options for the redesign resulting from the analysis have been evaluated against the design criteria, the accompanying risks, and the user preferences. The power relation between energy efficiency and the comparable Life Cycle score has gained the highest scores and will therefore be used in the redesign. This relation is shown in Figure 0-1.

![Figure 0-1 Power relation energy efficiency and comparable Life Cycle score](image)
The redesign is a Performance Measurement System, meaning the system (software, databases and procedures) to execute performance measurement is described. The redesigned software is an Excel based tool executing two processes (i.e. the GFA Environmental Benchmark and Life Cycle approach) (see Figure 0-2). The outputs of the tool are a numeric and visual comparison between the new and the reference product and the accompanying Green Product classification. A database, which has been developed in the analysis phase and includes all 968 products of the representative sample, is linked to the tool. The procedures have been described together with instructions for use. A plan for the implementation of the redesign is given as well.

Conclusions
Reflecting on the tool leads to the main conclusions of this project:

- Since the redesign combines two processes into one process, process has become more efficient. The tool developed for these processes estimates a Life Cycle score, which means a lot of time is saved (i.e. the time needed to perform a LCA). The tool is able to classify a large amount of products in a reasonable time. Therefore, it can be said that the goals set are accomplished.
Most design criteria are fulfilled, the problems found in the problem analysis are solved when implementing the redesign, the steps defined in the project assignment are executed, the research questions are answered, and the deliverables are gained.

The redesigned tool could be used for more purposes than the one it is designed for. The input-output screen offers an easy way to see the results of improving a certain parameter immediately. Therefore, it could be of a great support in the EcoDesign procedures of the product development process.

Some limitations in the process and redesign are found in the reflection as well:

- The validity of the option for the simplification of the process is a weakness since it was not possible to test on a representative sample. This also affects the duration of the validity of the tool since it might be possible that the estimating formula is not valid for new technologies.
- Testing is only done in the BG Lamps, which means implementation in all BG’s is not possible (yet).
- The amount of hazardous substances has two factors while only one of them is included in the redesign.
- The database does not include all products, which limits the possibilities for reference products.
- No clear conclusions could be drawn on the possibility of product clustering in the Green Product classification process.
- The literature available was not satisfying since it lacked information on specific subjects.
Preface

At Eindhoven University of Technology every Industrial Engineering and Management Science student finishes his or her studies with a graduation project either at a company or at university. This report is the product of a seven-month graduation project executed at Royal Philips Electronics. It is meant as a thesis to gain the Master of Science degree and as a delivery for the company where the project is executed.

This project is about categorizing Green Products at the sector Lighting. Besides the company and the research assignment, this report describes the problem diagnosis and the analysis of the current process of classifying products as Green at Philips Lighting. Theory (literature) and practice (case studies and interviews) have been analysed. The conclusions of this analysis have lead to several options for the redesign of the classification process of Green Products. The most suitable redesign option is worked out and presented in this report together with instructions for use and an implementation plan.

During my graduation project, which was not always easy, I have received a lot of support from different people. Therefore, I would like to use the opportunity to thank some people. Firstly, I would like to thank my Philips supervisor Maarten ten Houten for his support, for always being willing to listen to my questions and to give advice. I would also like to thank my principal Frank Altena for giving me the chance to execute my graduation project at the Philips Lighting Sustainability Team. Furthermore, I would like to thank Allard Kastelein for being a great support as my university supervisor, and for all the reading and listening. I would also like to thank Fred Lambert, my second university supervisor, for his time and feedback. Finally, I would like to thank all other Philips and university people who helped me during the project for their time and willingness to help.

I would also like to thank some people for their personal support during all years of studying, especially the last seven months. I would like to thank all my friends, who really helped me through some tough periods. Furthermore, I would like to thank my mum and dad for always having faith in me. I would like to thank my sister for her interest and support. And finally, I would like to thank my boyfriend Roel. Without his support, encouragement and trust it would have been far more difficult. I am very glad to have such wonderful people around me!

This report is the last product of my seven years as an Industrial Engineering and Management Science student. I hope you will enjoy reading it just as much as I enjoyed my time as a student!

Eindhoven, 8-9-2008

Lieke van Amelsfort
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1 Introduction

This introducing chapter describes some background information on the subject of this project, showing its topicality and difficulty. Hereafter, the structure of the remaining report is described.

1.1 Subject of the project

Sustainability is a complex and relative issue since it varies according to countries and companies (Jacquot et al., 2005). Philips uses the definition of the Brundtland Commission report of 1987 (Chronos training). Therefore, sustainability in this project is defined using the same definition: meeting the needs of our generation without compromising the ability of the next generations to meet their needs (WECD, 1987).

According to the Brundtland Commission report sustainable development is the path to sustainability (WECD, 1987). It is the simultaneous pursuit of economic prosperity, environmental quality and social equity. Therefore, sustainable development is built on three pillars: people, planet and prosperity (the Triple Bottom Line). Sustainable development is about many things that one can not necessarily see, that relate to people in complex and unpredictable ways, that emerge over a time span of centuries, that challenge the conventional thinking and that causes one to rethink the values hold (Chronos training). It is the search for a dynamic balance between the three dimensions of the Triple Bottom Line. Therefore, the definition can evolve over time. It is already making its way towards 'sustainable social growth' with the world heritage of knowledge as restriction factor instead of the environment (Jacquot et al., 2005).

There are four common responses to sustainable development in industry: denial, compliance, opportunity and commitment. Leading companies that are already committed, such as Philips, regard sustainable development as a strategically important goal. Most major decisions in the company reflect a commitment to environmental and social responsibility. Awareness of global challenges and emerging trends in society is strong, boosted in part by a high level of interaction with a broad group of stakeholders, and active engagement with the issues (Chronos training).

1.1.1 Topicality subject

A lot of attention is being paid to sustainability issues nowadays. Especially Al Gore’s work, ‘An Inconvenient Truth’ raised a lot of awareness concerning sustainability (Gore, 2006). During this project, several headlines in the news demonstrated the topicality of the many-sided subject sustainability for businesses, and for Philips specifically:

- ‘Sustainability? Few consumers know what it is’ (Dag, 2008-04-04)
- ‘Philips scores badly on environmental issues’ (Sustainability news, 2008-04-16)
- ‘The climate problem is favourable for Philips’ (De Pers, 2008-06-02)
- ‘Businesses are behind with sustainable entrepreneurship’ (Sustainability news, 2008-06-30)
- ‘Old televisions of Philips also end up on garbage dump in Africa’ (Volkskrant, 2008-08-05)

1.1.2 Significance subject for Philips

Sustainability is a broad subject. This project is about Green Products, one of the many aspects of sustainability. Companies that are leaders on the Green Products market will have a
competitive advantage compared to their competitors in terms of innovation and market share (Jacquot et al., 2005). This should be materialized by an improvement of the economic and financial performance in the medium and in the long term.

Green Products are significantly better for Philips, but also for the environment and the consumers. The environment benefits as it will be less polluted. Furthermore, the consumers will benefit, as they will have lower total cost of ownership for their products since the total life cycle costs will decrease. The initial investment could be higher, but this amount is gained back in lower electricity usage costs. Philips benefits since their products have more added value. Putting Green Products on the market can therefore be seen as a triple win situation. However, to be able to put a large amount of Green Products on the market, a robust and efficient process for classifying products as Green is needed.

1.1.3 Green debate
There is a lot of debate going on about the subject 'Green'. For customers, it might be difficult to understand why one product is Green and another is not. It should be avoided that customers perceive a Green Product as being good for the environment since this is not true. A Green Product is always relative, which means it damages the environment less than other products. Within Philips, a product is Green when it performs significant better than a reference product during the whole Life Cycle (see paragraph 2.4). To be able to prevent this misunderstanding, it is very important to give attention to the communication of Green Products and the underlying classification process.

1.2 Structure of the report
The report starts with a description of the company where the project is executed, Royal Philips Electronics, and its sector Lighting, sustainability within Philips and more specifically within Lighting, and the process under consideration. Chapter 2 describes the relevant aspects concerning the research assignment, such as the inducement and the goal, and the results of the problem diagnosis resulting in the project assignment. The project approach (methodology and research model) is reported on in the next chapter. Hereafter, chapter 5 presents the results of an analysis of the Green Product classification process. It discusses the history of Green Products, and the relevant aspects of the process within Philips and in literature. Case studies have been analysed. The results of these analyses and the accompanying results are shown in chapter 6. The last chapter describes the redesign of the process and an implementation plan. Finally, the conclusions and recommendations are given.

1.2.1 Quick reading guide
Philips employees are familiar with the subject. Therefore, it is not necessary for them to read the whole report to be able to understand the essence. To assist them in selecting the relevant parts, a quick reading guide is included for them. As well in front of the (sub-)chapter name in the table of contents as in front of the (sub)chapter title in the report Figure 1-1 indicates the parts that should be read to fully understand the core of the project without having to read everything.
2 Company description

This chapter first gives a brief introduction to Royal Philips Electronics. Hereafter, the sector Lighting is described. Sustainability within Philips, and specifically within Lighting, is described in the next section. Finally, the process under consideration is described.

2.1 Royal Philips Electronics

Once started as a lighting company making carbon-filament lamps in The Netherlands in 1891, Royal Philips Electronics N.V. nowadays is a global leader in the sectors Healthcare, Lighting and Consumer Lifestyle. Philips, with its headquarters located in Amsterdam, had sales of € 27 billion in 2007 and employs approximately 124,000 employees in over 60 countries worldwide. Following the brand promise 'sense and simplicity', Philips continuously explores new ways to improve products and to offer innovative products to its consumers, trying to deliver advanced, easy to use products that are designed to meet all consumers' needs all over the world. Philips' mission is to improve the quality of people's lives through timely introduction of meaningful innovations. 'In a world where complexity increasingly touches every aspect of our daily lives, we will lead in bringing simplicity to people' is their vision. Philips' strategy, called Vision 2010, aims to further position Philips as a market-driven, people-centric company with a strategy and a structure that fully reflect the needs of its customer base, while also increasing shareholder value. Furthermore, Vision 2010 aims to fuel growth through sharpened strategies for Philips' three core sectors in a simplified business structure: Philips Healthcare, Philips Lighting, and Philips Consumer Lifestyle (since January 2008). The Philips values (delight customers, deliver on commitments, develop people and depend on each other) are also a vital part of the Vision 2010 initiative. The brand promise is to make easy to experience, designed around you and advanced products.

2.2 Philips Lighting

Philips Lighting is the leader in the global lighting market, a position supported by leadership in innovation combined with a systematic approach to seeking out new market opportunities. Lighting's mission is to understand people and improve their lives with lighting. 'Being the Clear Leader: setting the pace in the industry' is their vision. Philips Lighting, with its headquarters located in Eindhoven, employs approximately 55,000 people worldwide. The sector maintains sales and service organizations in over 60 countries and runs manufacturing operations in 14 countries. Commercial activities in other countries are handled via dealers working with the company’s Lighting International Sales organization. The principal markets are Europe, North and South America and Asia Pacific. In 2007 sector's sales grew to € 6.1 billion (see Figure 2-1).

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2 All information in sections 2.1, 2.2 and 2.3 is derived from Philips Internet, Intranet and / or publications
Philips Lighting is structured in six business groups (since January 2008), namely Lamps, Professional Luminaires, Consumer Luminaires, Lighting Electronics, Automotive & Special Lighting Applications, and Solid State Lighting Components & Modules. All units are organized on a regional basis in the principal markets.

Each business group of Philips Lighting serves as well businesses as end-consumer customers, except for the two luminaires business groups. The division of sales is about equal, 50% of the Lighting customers are businesses and 50% of the customers are end-consumers.

Lighting's product portfolio contains about 27,000 products. It includes a full range of incandescent and halogen lamps, compact and normal fluorescent lamps, high-intensity gas-discharge and special lamps, fixtures, lighting electronics, ballasts, light-emitting diode-based lighting (LED) and automotive lamps. The sector's products are found all over the world: not only everywhere in the home, but also in a multitude of professional applications.

There are three major players on the global lighting market. Philips' two main competitors (Osram GmbH and General Electric (GE)) are shortly described in appendix I.

2.2.1 Trends
As the world's leader in Lighting, Philips is driving the switch to energy-efficient solutions, as well as shaping the future with exciting new lighting applications and technologies. The lighting industry faces significant changes, giving Philips ample opportunities to shape their own future by showing leadership. There is a transformation from conventional light sources to solid-state lighting. The long lifetime of solid-state will diminish the need for lamp replacement, and together with its small size and robustness will create complete new lighting solutions for yet unsatisfied people needs, what was never before possible. Furthermore, there is the fast economic growth in emerging markets like Brazil, Russia, India, China and Asia, which makes it possible for Philips' leadership to be expanded in those countries. The rise of the energy prices and climate change awareness results in increasing requirements for energy saving solutions, to which Philips' innovative lighting solutions can contribute significantly. To take full advantage of the transformation Philips will proactively move closer to the end-user application by increasing their presence in professional and consumer luminaire-systems, enabling them to expand on their leading position in solid state lighting, where necessary by acquisitions.
2.3 Sustainability within Philips

The quote of Gerard Kleisterlee (September 2007) shows Philips’ dedication to sustainability: ‘We believe that big changes start small and that every one of us should contribute to saving our planet’. Already at the very outset of the company, Anton and Gerard Philips, the founders of the Philips concern, really cared for sustainability. With a tradition of sound environmental policy for more than 30 years, Philips is guided by the basic principle that prevention is better than cure.

Philips focuses on the Triple Bottom Line: people, planet and profit. This means Philips is balancing economic prosperity, environmental quality and social equity. The company’s sustainability strategy is to focus on energy efficiency and healthcare. Key Performance Indicators (KPI) are defined for sustainability overall and in each sector. This way, sustainability is an integral part of Philips’ strategies, products, manufacturing processes, and day-to-day way of doing business. For Philips, the value case of sustainability is easy to make, as the business benefits are clear: lower risk, brand strength, reduced costs, motivated employees, and potentially more profits.

Since 1994, Philips has run several environmental programs, covering both production and product development. With these so called EcoVision programs, Philips established coordinated, measurable programs to install environmental responsibility and implementing sustainability into all processes and procedures of product design and development. EcoVision focuses on the reduction of energy, emissions, waste and water. This translates into targets, which mean for example that wherever possible, Philips’ product packaging must be reusable or recyclable. The aims of the fourth EcoVision program for 2012 are to double total revenues from Green Products (see paragraph 5.1.2) to 30%, to double investments in Green Innovations to € 1 billion and to improve its operational energy efficiency by 25%.

Philips’ sustainability strategy is to become the recognized leader in sustainability. The proof points are to achieve a top ranking in the Dow Jones Sustainability Indexes and other ratings for investors, to offer a portfolio of sustainable products and services, to be perceived as a sustainable employer of choice for employees, to engage in stakeholder dialogue on social and environmental issues, and to create economic value for shareholders. Some Philips sustainability facts are listed in appendix II.

Within Philips, sustainability is organised via a separate line. There is a corporate sustainability team, and there are sustainability departments in all three sectors. Within Lighting, sustainability is coordinated by the Sustainability Support Team.

2.3.1 Sustainability within Lighting

In line with its mission and vision, Philips Lighting will act at all times as a responsible corporate citizen wherever they do business. Philips Lighting will strive to continuously and simultaneously improve its economic performance, environmental efficiency and social impact and reinforce its leadership position. Lighting’s policy is derived from the Philips corporate policy on sustainability. All parts of Philips Lighting are required to implement this policy and to actively encourage suppliers and contractors to do so.

The Green Switch is the Philips Lighting program to speed up the switch towards energy efficient lighting solutions. Nowadays, energy and climate challenges are increasingly gaining
attention. As lighting represents 19% of the global electricity consumption, an accelerated switch to energy efficient lighting contributes significantly to reducing global CO₂ emissions while offering an opportunity for profitable growth in all regions and segments, and at all levels of society (www.asimpleswitch.com). This represents a unique ‘triple win’ opportunity. Users save cost and have better light quality, the environment benefits from lower energy use and CO₂ emissions, and the lighting business benefits from increased market value growth. New innovative lighting solutions could realistically save up to 40% energy on all today’s installed lighting. Global savings of € 106 billion in energy costs per year can be reached. Philips provides advanced energy-efficient solutions for all segments: road lighting, office & industrial, hospitality and home. In 2007, as much as 46% of the total lighting sales were ‘Green’ sales (www.asimpleswitch.com).

2.4 Current Lighting Green Product classification process

Within Philips Lighting sustainability is ideally an integral part of the innovation funnel (see Figure 2-2). Several sustainability requirements are translated into Green targets for Philips and its sectors and into Green Product definitions. In the development process these requirements are integrated in validated Value Proposition Houses (VPH) (see appendix III - A). A legal check of the claim proposal (see appendix III - B) and several sustainability checks (at the milestones of the development process) take place subsequently (see appendix III - C). Data is underpinned and verified by the use of a benchmark (see paragraph 2.4.1). The Sustainability Support Team is responsible for the internal validation of this benchmark. The products that pass this step are seen as Green Sales. Green Sales can either be products that are branded as Green (with a logo) or products that are not branded as Green (no logo). External validation is done by a third party. The Green Branded Products should lead to net promoters, which causes an increase in the Net Promoter Score (NPS) (see appendix III - D).

Positioned in the innovation funnel, the steps of the current Green Product classification process are summarized in a flowchart of the process (see Figure 2-3). All the arrows represent mandatory 'and / and' relations. One exception is the dotted line, which represents an optional relation. The grey square depicts the scope of this project (see paragraph 3.3.2).
The process starts with New Product Development. In the development process, roadmaps for products are set, which eventually lead to a validated VPH. After the described checks, a candidate product can start the Green Product classification process a few months before...
launching a new product. The candidate product needs to be tested. Therefore, (a) reference product(s) is / are needed. These are functional comparable products (commercial competing products, Philips predecessors or other products in the family / category). After selecting the reference product(s), the candidate and reference products enter two processes: Life Cycle approach and GFA Environmental Benchmark. These processes are explained beneath. Inputs for these processes are product data and measurement reports (for example development measures or results of market research). A Life Cycle Assessment (LCA) can be executed as underpinning of the Life Cycle approach, but this is not necessary. LCA is not only used for this purpose but also as a part of the Philips Strategy Vision 2010, to seek innovation opportunities and / or as a part of general benchmarks. Therefore, a LCA report is an outcome of this process.

A candidate product can be classified as a candidate Green Product if both an improvement in the Life Cycle Score and either 'a 10% improvement in energy efficiency and at least an equal score on hazardous substances' or 'a 10% improvement in hazardous substances and at least an equal score in energy efficiency' are obtained. If one of the two conditions is (or if both conditions are) not fulfilled, the candidate product is not a Green Product.

The candidate Green Products enter the process of a third party review. If the third party validates the Green Claim, a product is classified as a Green Product. Otherwise, it is not classified as a Green Product. The Green products enter two processes: checking whether a product is Green according to the customers' perception and executing a Brand Risk Assessment. A Brand Risk Assessment checks whether branding a product as Green could have a negative impact on Philips' image (e.g. although 25% of energy is saved a product can still be environmentally unfriendly). If the Green Product passes both processes, the product is classified as a Green Branded Product. If one of the two processes has (or if both processes have) a negative outcome, the product cannot be branded as a Green Product.

2.4.1 Philips’ Green Focal Area (GFA) Environmental Benchmark

Philips makes use of six Green Focal Areas (see Figure 2-4). Each sector defines metrics for each focal area (Philips Internet, Intranet and publications).

![Figure 2-4 Philips' Green Focal Areas (Philips publications)](image)

The environmental benchmark compares a Philips product with functional comparable products (reference products), which can be commercial competing products with the same functionality, Philips predecessors (product or dominant technology) or other products in the family / category. When compared with more than one competitor, the product is compared to an average of the competitors' performance in the investigated focal areas. The Environmental Benchmark is structured following the GFA (see appendix IV). The GFA Recycling and Disposal makes use of the Eco-Indicator score, which is explained in paragraph 2.4.2.
2.4.2 Philips' Life Cycle approach (LCA)

Every product damages the environment to some extent, with raw materials extraction, manufacturing, distribution, packaging, usage and/or disposal. The Life Cycle approach consists of the qualitative life cycle reasoning and/or the Life Cycle Assessment (LCA). The qualitative life cycle reasoning is used when LCA results are predictable based on existing LCA knowledge. LCA is a technique for assessing the environmental aspects associated with a product over its life cycle. LCA is a holistic, integral approach, which fits within the procedures of the ISO 14040 series. The most important applications of LCA are the analysis of the contribution of the life cycle stages to the overall environmental load with the aim to prioritize improvements on products or processes and the comparison between products for internal communication. A LCA consists of four steps, which are interacting with each other (Philips publications):

1. Defining the goal and scope of the study,
2. Making a model of the product life cycle with the environmental inflows and outflows. This step is called Life Cycle Inventory (LCI),
3. Understanding the environmental relevance of all inflows and outflows. This step is called Life Cycle Impact Assessment (LCIA), and
4. Interpretation of the study.

The scope of LCA's at Philips is cradle to grave. Cradle to grave is the full LCA from extraction of materials and resources (cradle) to the use and disposal phase (grave). Within Philips, two software programs are used to perform LCA's. SimaPro is a professional, very detailed software package, which is used by Philips experts at the Philips Environmental & Safety organization only. EcoScan is a software tool, which assists in creating a simple model of a product or process. It uses a database, which is distributed only within Philips and is calculated and maintained by the Philips Environmental & Safety organization using SimaPro. The database contains information on materials, processes, energy, transportation, components, packaging materials and end-of-life information (e.g. recycling, landfill or incineration processes) (Philips publications).

Philips uses one of the several methods for calculating the life cycle impact, the Eco-Indicator (see appendix V). The Eco-Indicator is a single score representing the overall environmental impact of a material, process or product (see Figure 2-5). It is a dimensionless figure with the name 'Point' [Pt], where 1 Pt represents one thousandth of the yearly environmental load of one average European inhabitant (Philips publications).
Figure 2-5 The Eco-Indicator 99 calculation process (Philips publications)
3 Research assignment

This chapter first describes the inducement of the problem and the problem itself. The problem diagnosis is explained next, resulting in the project assignment and accompanying goal, scope, research questions, and deliverables.

3.1 Inducement

Philips’s Chief Executive Officer Gerard Kleisterlee decided one of the main pillars in Vision 2010 is Green Products Sales. With the start of EcoVision IV in September 2007, an emphasis should be put on promoting Green, which is expressed in the goals set (achieving a duplication of the total revenues from Green Products and a duplication of the investments in Green Innovations by 2012). Therefore, more Green Products need to be put on the market. Additionally, Philips’ Group Management Committee decided in 2007 to introduce the term Green Products instead of Green Flagships. Therefore, a new (high level) definition has been made for Green Products. Moreover, in 2007 46% of Lighting’s sales were Green. This means Green Products are becoming mainstream, which makes explaining the Green classification a major issue for Philips Lighting (see Table 3-1).

<table>
<thead>
<tr>
<th>Year</th>
<th>2006</th>
<th>2007</th>
<th>2008*</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR million</td>
<td>% of total sales</td>
<td>EUR million</td>
<td>% of total sales</td>
<td>EUR million</td>
</tr>
<tr>
<td>Philips Group</td>
<td>4000</td>
<td>15.0</td>
<td>5286</td>
<td>19.7</td>
</tr>
</tbody>
</table>

Table 3-1 Sales of Green Products (Philips publications)

* based on expected 5% sales growth

These developments make it necessary to (re)test all products on being Green. However, the current process to classify products as Green is very time consuming. Therefore, there is a need for an efficient method to classify a large amount of Green Products, which would help Lighting to reach the targets set in EcoVision IV.

3.2 Problem analysis

The initial problem to be solved within this project is: ‘In the current practices concerning Green Products, there is a gap between Philips’ objective to have more Green Products and the used tools to classify products as such’.

The initial problem definition mentions the existence of a gap. To be able to solve the initial problem, it is essential to find out more about this gap and its causes. The Stream Analysis technique (Porras, 1987) is used to do this and to diagnose the problem (see appendix VI). The result of this method is a graphic representation of the problem in a chart, showing the complex set of relations between causes that are divided into several columns that represent categories (Porras, 1987). This chart allows an effective presentation and understanding, and it facilitates remembrance. The chart can be used in several key stages of intervention as a communication driver (Porras, 1987). A major advantage of this method is that it is not bound to one type of organization setting. Rather it is a tool that has to be adapted to a situation (for example in choosing different categories). The method is very suitable in this project since it allows for several interconnections between causes and since it gives the opportunity of clustering causes into categories.
The analysis of the problem chart resulted in the identification of symptoms and root causes. Five root causes of the existence of the gap could be identified:

1. Within Philips Green is not a leading principle in all business parts yet (e.g. no separating of rubbish in offices),
2. Within Philips Green Product definitions and classification processes have been subject to many changes and adaptations,
3. In the current Philips Lighting Green Focal Area Environmental Benchmark the guidelines for the choice of reference products are not clear and strong enough,
4. Within the current Philips Lighting Green Focal Area Environmental Benchmark the guidelines regarding the input criteria are not clear and strong enough, and
5. Within Philips Lighting there is not a single database containing information on standard materials and amounts.

The problem definition for this project is derived from the identified root causes since it makes no use to solve symptoms without looking at their causes. Two of the root causes (1 and 2) are out of reach for this project since they are Philips wide culture and organizational causes. Including the remaining three root causes, the problem definition for this project can be defined as follows:

In the current Philips Lighting Green Focal Area Environmental Benchmark the guidelines regarding the input criteria (the quantitative composition of products) and the guidelines for the choice of reference products and are not clear and strong enough. Furthermore, a single database containing information on standard materials and amounts does not exist within Philips Lighting.

### 3.3 Project assignment

A project assignment formulates what needs to be done in a project. In this project, the problem definition needs to be solved. Therefore, the project assignment is formulated as follows:

Redesign the process of the classification of Green Products. In order to do this, evaluate the current classification process, set requirements for the redesign of the process, explore options to adapt or replace the current process, and design options for an efficient tool to classify the whole Lighting product portfolio that make external verification possible.

### 3.3.1 Goal

The goal of this project is to redesign the process of classifying products as Green in such a way that it complies with Philips' Brand Promise 'Sense and Simplicity'. The process needs to become more efficient, being able to classify large amounts of products in a reasonable time.
3.3.2 Scope

There are three requirements a Green Product has to fulfil to be branded as such, i.e. to deserve the Green Logo (Philips publications, see paragraph 2.4):

1. A Green Product has to answer to the definition of Green Products (objective),
2. The Green benefits of a product have to be recognized by customers (customers’ perception, subjective), and
3. A Green Product has to pass a Brand Image Risk Assessment (although 25% of energy is saved, a product can still be environmentally unfriendly).

Market Intelligence researches the second condition, making an inventory of customers’ problems and dilemmas. The process to fulfil the third condition is under development. Therefore, the processes to fulfil these conditions are out of the scope of this project. The focus of this project will be on the objective classification of products (making justifiable Green claims) following the Philips (high level) definition of Green Products, using the Lighting conditions. In other words, the scope of this project is the part of the process from the status Candidate Product until the status Green Product / Green Sales (see grey square in Figure 2-3). However, it is very important to exchange information with the designers of the last two requirements. This exchange of information makes it possible for both parties to use results of the others as input.

There are several conditions that apply to this project assignment:

- The tool should be designed for the long term,
- The norms (the reference product scenario) are set for the middle long term, as there might be a need for adjustments,
- The tool needs to be applicable for products for both businesses and end-consumers, and
- The data should be available and easily accessible since an independent external verification should be possible.

3.3.3 Research questions

The project assignment is supported by several research questions that need to be answered during this project:

1. What are the conditions for an efficient classification tool based on the whole life cycles of products?
   a. What is the duration of the validity of a Green classification?

2. What quality requirements do input data need to fulfil for the Green Product classification tool?
   a. What input data is needed for what reasons?
   b. How, when and by who can this data be obtained?
   c. Where can the data be stored?

3. What conditions do the reference products have to fulfil?
   a. What is the duration of the validity of the norms (the reference product scenarios)?
4. What are the key denominators for the environmental performance of Lighting products?

5. What tolerance is permitted in the outcomes of the tool maintaining a reasonably accuracy?

6. Which product clustering can be justified in accordance with the outcomes of the tool?
   a. How can a significant difference in outcomes be assured between the product clusters?

7. Which data is needed for an independent third party to verify the Green classification?

3.3.4 Deliverables
The deliverables of this project are:

- Answers to the research questions,
- Designs of validated scenarios (including accompanying risks) for an efficient tool to classify Lighting's product portfolio,
- Instructions for use of the norms and the tool, and
- Implementation plan for the tool.
4 Research approach

This chapter describes the methodologies used for this research and the accompanying research approach.

4.1 Methodology

Philips strives for business excellence. Therefore, they use a Total Quality Management (TQM) Strategy named 'Business Excellence by focussing on Speed and Teamwork' (BEST). Within BEST, a tool named MEDIC (i.e. Map & measure, Explore & evaluate, Define & describe, Implement & improve, Control & conform) is used for systematic business process improvement (see appendix VII). MEDIC consists of five steps that together provide the discipline and common language for improving process performance. It provides a structure for delivering sustainable, excellent performance in running and completing improvement projects. To make sure the process fits within Philips’ standards, the chosen project approach has to match the MEDIC tool.

The process of this project (evaluating the current classification method, learning of this evaluation, and developing an adjusted tool from the lessons) fits the model of an organisation that is learning and evolving. Kastelein’s regulation circle of changes of organizations shows how organisations change (see Figure 4-1). It reflects the importance of measuring and comparing, which are essential elements of processes in the organisation and in the determination of necessary changes. Therefore, the decisions of what to measure and compare should not be underestimated. Vollman (1996) gave a description that reflects Philips’ intentions of classifying Green Products: ‘measures and Key Performance Indicators (KPI) are basically how an organisation describes itself (its performance) to itself. It ‘teaches’ itself through these tools about success and failure, and it behaves accordingly’. Philips has set several KPI’s for sustainability. This method is very suitable for this project since the measuring tool is the subject of this project and the steps from the regulation circle that will be executed match the steps of the MEDIC tool.

![Figure 4-1 Regulation circle of changes of organisations (Kastelein)](image)

The organization process, which is in this case the current Lighting Green Product classification process, is analysed. Measurements on this process are carried out and the outcomes are compared to the current way of classifying Green Products. This has led to options for the simplification of the classification process. The norms (reference products) are defined. In the judgement phase the best simplification option is selected. Hereafter, a plan for a redesigned
4.2 Research model

The regulation circle methodology needed to be made concrete in order to serve as a support in the project approach. Verschuren and Doorewaard (1995, in Van Aken et al., 2003) suggest the usage of a research model to give an overview of the project approach. The research model of this project is shown in Figure 4-2.

As can be seen this project is structured in three phases: orientation, analysis and redesign. In each phase different approaches are used. Therefore, each phase and the approaches used within each phase are described in separate subchapters.
4.2.1 Orientation phase
Desk research, studying literature and interviewing employees were the activities executed in the orientation phase. These activities have led to insight in the sustainability subject (chapter I) and in Philips, its sector Lighting, sustainability within Philips and specifically within Lighting and the Green Product classification process (chapter 2). Porras Stream Analysis (see appendix V) was executed to diagnose the initial problem, which resulted in the project assignment as described in chapter 3.

4.2.2 Analysis phase
To be able to come to options for simplification of the current Green Product classification process insight in the structure of the current classification process is needed as well as insight in the actual product evaluations. In the analysis phase, the current Lighting Green Product practices were thoroughly analysed by combining the desk research of the orientation phase with additional literature and interviews with employees (see chapter 5).

The insight in the actual product evaluation is gained through case studies. The approach plan for the case studies is shown below (see Figure 4-3).

The first things to do were inventory and update all available data. As can be seen in Figure 4-3, the steps 2 through 5 are an iterative process, which continually improved the quality of these data. Hereafter, a case study sample is defined to execute several analyses on in the search for options for the simplification of the process. The analyses executed are presented in Figure 4-4.

Each analysis is briefly explained here. Chapter 6 provides a more elaborated explanation together with the results of the analyses (hypothesized options for simplification of the classification).
A. A centre of gravity analysis determines the key denominators in the scoring of Green Products.

B. In the analysis of the Life Cycle scores relations between the various phases of the Life Cycle and the total Life Cycle score are searched for. The sensitivity analysis searches for the relation between the input parameters and the score of each of these phases.

C. This analysis examines for which characteristics it is possible to distinguish statistically between Green Products and non Green Products.

D. In the discriminant analysis a discriminant formula is developed that predicts whether a Product is classified Green or not.

E. The characteristics influence each other. This analysis looks for statistical significant relations between these parameters.

F. Several technologies are used within Lighting. This last analysis investigates whether it is possible to classify whole technology based clusters as Green Products or non Green Products.

The six analyses have led to five hypothesized options for simplification of the classification process. These hypotheses needed to be checked (see Figure 4-5).

The three tests are introduced here but are explained more extensively in chapter 6.

I. The hypotheses have been checked with a representative sample whenever possible. Unfortunately, it turned out not to be possible to test all hypotheses this way. Therefore, the two other tests have been used as well.

II. The abnormality test compares the actual outcome values with the outcome values calculated using the hypotheses.

III. The sanity check compares the outcomes of a professional detailed analysis with the outcome values of a simplified analysis and the outcome values calculated using the hypotheses.

The tests resulted in four accepted hypotheses, i.e. four options for the simplification of the Green Product classification process. These options can be used for the redesign of the process.

4.2.3 Redesign phase

In this phase literature and interviews have resulted in several design criteria, which the redesign needs to fulfil. Each option for redesign is analysed on the fulfilment of these design criteria, the accompanying risks and the user preferences. Grading each option on these three aspects has led to the choice for one option for redesign. This option is worked out and presented together with the accompanying procedures, instructions and an implementation plan in chapter 7. A reflection and a discussion are also presented in this chapter. Finally, some conclusions and recommendations are given in chapter 8.
5 Results analysis Green Product classification process

This chapter first describes the history of Green Products at Royal Philips Electronics. Hereafter, the different aspects of the Green Product classification process that are in the scope of this project are explained more extensively. Finally, literature findings related to the classification process are summarized.

5.1 History Green Products

The first realization that products as well as production processes could have an environmental impact came a long time ago. The first application in assessing Life Cycles is the Resource and Environmental Profile Analysis (REPA), which took place in 1969 already. The Life Cycle Assessment (LCA) as known nowadays is the successor of this method (see paragraph 5.3.2). The method became more accepted and ultimately standardized as a result of the involvement of the Society of Environmental Toxicology and Chemistry (SETAC) at the beginning of the nineties of the 20th century (Lambert, 2007).

The acknowledgement of the impact of products on the environment was supported with the publication of the Brundtland report ‘Our Common Future’ by the United Nations (WECD, 1987) at the end of the eighties. Philips was one of the first movers in the field, starting the development of EcoDesign in 1993. EcoDesign is defined as ‘design to improve environmental properties of products’, i.e. Green Products design (Stevels, 2007). The development of EcoDesign started with design manuals, evolving to a structured methodology for attuning environmental considerations to the business strategy of Philips in 1997 (Stevels, 2007).

In 1995 the BayGen Clockwork radio was introduced on the market, a radio that is powered by a clockwork wind-up mechanism driving an internal electrical generator, which makes it self-sufficient. Philips’ designers reacted on this product with their own human powered radio (AE1000) and the development of a Green TV. Cor Boonstra, then the chairmen of the management board, saw the opportunity of the Green TV: enhance the image of the company through such products and reach out to a group of customers not addressed so far by Philips. He decided that each Business Group needed to have at least one Green Flagship (see paragraph 5.1.1), such as the Green TV, in its product portfolio. This was included in the sustainable strategy EcoVision (Stevels, 2007).

In 2007, Philips’ Group Management Committee decided to use the term Green Products instead of Green Flagships for more customer clarity. Therefore, three terms are nowadays known within Philips: Green Flagships, Green Products and the Green Logo. Each will be explained beneath.

5.1.1 Green Flagships

The product development part of the EcoVision program is called EcoDesign. Part of the EcoDesign process is a product assessment where additional environmental improvement options are explored and targets and objectives are set. In the EcoDesign approach, focus is on the Philips Green Focal Areas (GFA): energy efficiency, packaging, hazardous substances, weight, recycling and disposal, and lifetime reliability (see Figure 2-4). To be considered a Green Flagship, a product must first go through divisional EcoDesign procedures. Based on this analysis, it must be proven that the product or product family offers a significantly better (10% improvement or more) environmental performance in at least one Green Focal Area, resulting
in a lower total environmental impact. Next to this, an improvement in the overall Life Cycle Score needs to be gained as Philips uses a Life Cycle approach to determine a product’s overall environmental improvement (see paragraph 2.4.2). More than 200 Green Flagships are on the market, about 50 of which are Lighting products (Philips Internet, Intranet and publications).

5.1.2 Green Products
The name Green Flagship is replaced by the name Green Product since 2007. The high level definition of Green Products as agreed by the Group Management Committee of Philips is: ‘Philips Green Products have a significant improved environmental advantage for customers, users and society in one or more of the Philips Green Focal Areas. Green Products are identified on specific divisional criteria by a division. Green Branded Products are independently reviewed by a third party’ (Philips publications).

5.1.3 Green Logo
The Green Logo (see Figure 5-1) is Philips' communication towards customers. Products with a Green Logo are Green Branded Products, so product that have passed all steps as described in 3.3.2 (Philips Internet, Intranet and publications and www.greenproducts.philips.com).

Figure 5-1 Philips Green Logo (Philips publications)

5.2 Analysis relevant aspects current Lighting Green Product classification process
As said in chapter 1 evaluating the environmental impact of lighting products is important for Philips for several reasons. First of all, sustainable business is seen as a corporate responsibility as well as a business opportunity. Furthermore, analysis of the environmental impact of products can create awareness at people as well inside as outside the company. Opportunities to reduce products’ scores in one or more Green Focal Areas can be found. Lastly, Philips must be prepared for new legislations concerning the environment.

The outcome of the evaluation of the environmental impact of products is a classification as a Green Product or as a non Green Product. Within the new definition of Green Products, every sector has to identify Green Products on specific divisional criteria per Green Focal Area, which are for Lighting:

- Energy efficiency: >10% less energy usage,
- Packaging: >10% less packaging in volume or weight,
- Hazardous substances & radiation: >10% less weight of one of the substances of the restricted and relevant substance list and / or >10% radiation dose reduction,
- Weight: >10% less product weight (including accessories),
- Recycling and disposal: >10% higher content of material that can be recycled and / or product that contains >30% recycled material, and
- Lifetime reliability: >10% lifetime improvement.
At Lighting a potential Green Product needs to be evaluated on at least energy efficiency (see paragraph 5.2.1), hazardous substances (see paragraph 5.2.2) and weight (see paragraph 5.2.3). To be classified as a Green Product one of these two criteria needs to be fulfilled and the Life Cycle score (see paragraph 2.4.2) should be better (Philips publications):

- 10% better in energy efficiency and at least equal hazardous substances, or
- 10% better in hazardous substances and at least equal in energy efficiency.

The following processes ensure the validation of the Green Product claim (Philips publications):

1. For each product (group) the Green Product claim is documented and underpinned,
2. Green Products sales are verified by KPMG,
3. Green Product claim is verified by a Third Party (in progress), and
4. Sectors hold regular Risk & Reputation Assessments on Green Products portfolio (minimum once a year). The objective is to check if environmental benefits are still valid due to changing (market) conditions or new product introductions. The assessment considers the voice of Philips business customers and end-consumers, market conditions, legislation, and voice of environmental groups. It validates if original claims still valid after a year.

Green Products will currently keep their Green status during their whole product life, unless a Risk & Reputation Assessment shows that the claim is not valid anymore. However, such an assessment is qualitative and subjective.

5.2.1 Energy efficiency
For the most important light sources LCA studies have been executed. From these studies it is clear that for lamps the usage phase is responsible for more than 90% of the total environmental effect (Environmental Technology Best Practice Program, 2000; DQE, 2008; PWC, 2004; Philips Lighting, 1992; Voermans, 1996; Kastelein, 1997; Bakx, 1997; Jansen and Stevels, 1998; Stevels, 2006). Therefore, energy efficiency is very important to include in evaluations of lighting products. A common measure for energy efficiency of lamps is energy efficacy, which is expressed in the amount of light output (Lumen) per power input (Watt).

5.2.2 Hazardous substances
The technology for some light sources is dependent on certain hazardous substances. Mercury is one of these substances. It is used in a lot in lighting technologies (e.g. in saving lamps and TL lighting systems). The use of mercury in lighting systems improves the efficiency. The problem is that mercury has the image of damaging the environment a lot, which makes it an important issue for stakeholders. However, it is not dangerous as long as it is inside the lamp. Mercury is important to include in the product evaluation since there is a risk that mercury is released to the environment, e.g. when someone drops the lamp or when a lamp is not disposed correctly in the end-of-life phase. Hazardous substances for lamps are expressed in milligrams of mercury that is inside the lamp.

5.2.3 Weight
A product's weight influences the environment in several ways. The heavier a product, the more materials are needed, which all have to be extracted from the environment. Also during
transport more damage is done to the environment due to the heavier product. Finally, in the end-of-life phase more weight means more materials to be disposed. This multi-impact weight has makes it a relevant characteristic to include in the evaluation of products. The weight of lighting systems is the sum of the weights of the various parts included in the system and is expressed in grams.

5.3 Literature tools environmental assessment

Many methods for environmental assessment are known. Common sense is the least sophisticated and accurate method, which takes least time. Environmental benchmarking (see paragraph 5.3.1) follows, where after (streamlined) LCA (see paragraph 5.3.2) follows. The most sophisticated and accurate form, which takes most time, is a full LCA (Stevels, 2006). As far as industry is concerned, the procedure of achieving an ecolabel does not include actually performing a LCA of a product. Instead, the overall environmental performance of the company and its suppliers should be of such quality that the criteria for achieving the ecolabel can be met (Jensen et al., 1997). Factors mentioned in literature that determine the success of measuring environmental damage are:

- An emphasis on customer service (Fussier and James, 1996),
- An emphasis on quality of life (Fussier and James, 1996), and
- A life cycle view (holistic approach) (Fussier and James, 1996; Stevels, 2006).

5.3.1 Benchmarking

Although benchmarking in business organisations is a relatively new concept, it has rapidly gained global acceptance as an instrument of continuous improvement in the context of TQM (Carpinetti and de Melo, 2002). Some environmental practitioners / researchers have become aware of the relationship between the environmental function / performance of organizations and that of quality (Sarkis, 2003). However, where the applications of benchmarking in the field of production processes have become common, the use of benchmarking concerning the environmental impact is still scarce (Diebäcker, 2000). For continuous environmental improvement to be successful the awareness of how well the organization is doing is very important, so the environmental performance of the organization needs to be determined and monitored (Sarkis, 2003). Benchmarking environmental performance has several advantages. It yields reproducible results (Stevels, 2006). It provides insight and awareness to the company as to where they stand in the market and to improvement options (Kolarik, 1995; Stevels, 2006).

More theoretical information on benchmarking is presented in appendix VIII – A.

Benchmarking has been defined as 'the art of finding out, in a perfectly legal and aboveboard way, how others do something better than you do-so you can imitate-and perhaps improve upon-their techniques' in Drew (1997). Drew (1997) distinguishes benchmarking practices according to the nature of the object being benchmarked and the partners with whom comparisons are being made (see Table 5-1).
Process benchmarking is used to compare operations, work practices and business processes whereas product / service benchmarking is used to compare product and / or service offerings. Strategic benchmarking is used to compare organizational structures, management practices and business strategies (Drew, 1997). Internal benchmarking is the comparing of performance between units / departments within one organisation (comparison can also be made of similar products / services of similar business units). Competitive benchmarking compares performance with direct product competitors (comparison can be made of products / services / business processes). Functional benchmarking is the specific function comparison with best practice (application of process benchmarking that compares a particular business function in two or more organisations in the same industry). Generic benchmarking means searching for the best practice irrespective of industry (similar to functional benchmarking but the aim is to compare with the best in class without regard to industry) (Drew, 1997). Benchmarking against competitors seems to be most widely used and is perceived as being the most successful (Drew, 1997). In deciding whom to benchmark, it should be taken into consideration that choosing partners who are too similar diminishes the opportunity for real learning, whereas choosing partners who are too dissimilar hinders comparative analysis (Diebäcker, 2000).

Environmental goals are critical to improving the environmental performance of products (Schvaneveldt, 2003). When the goals are specific and measurable it is possible to make comparisons and to measure progress (Schvaneveldt, 2003). Performance goals, comparisons, and measurement of improvement are also central themes of benchmarking (Schvaneveldt, 2003). Sustainability indicators are intended to answer the question how one might know objectively whether a company is moving toward or away from sustainability (Veleva, 2001). They are desired to be Specific, Measurable, Achievable, Relevant and Time bound (SMART) (Vogel, 2008). Furthermore, Veleva (2001) suggested the indicators should fulfil the following requirements:

- Manageable number,
- Appropriate to the task of evaluating sustainable practices,
- Based on available data and accurate data,
- Verifiable,
- Simple and yet meaningful,
- Developed through a transparent process, and
- Allowing for comparisons, among others.

### 5.3.2 Life Cycle approaches

Practical realizations of life cycle thinking in business strategies are numerous and include LCA, which ‘lays ground for design for environment, eco-labelling and environmental product declarations, supply chain management and environmental management systems’ (Mont and Bleischwitz, 2007). Therefore, life cycle thinking is helpful for companies in mapping out and reducing environmental impacts of their products and activities. It triggers companies to look
by the company gates in terms of problems and solutions, to transfer environmental awareness along supply chains and to create new incentives for environmental improvements (Mont and Bleischwitz, 2007).

The first scientific publication on LCA dates from 1992, where LCA is defined as ‘a method which allows the development of objective criteria and procedures for the assessment of the environmental impacts of products, based on the total Life Cycle of the product (from cradle to grave)’ (Klöpffer and Rippen, 1992). The purpose of LCA is to assess the possible environmental impacts of product substitutions, i.e. the choice of one product instead of another (Weidema et al., 2004). LCA is suited for investigating all products that consist of a manageable number of components. Which method to use must depend on the goal and scope in each case, inclusive target group, publication strategy etc. (Weidema et al., 2004). A LCA consists of four steps as mentioned in paragraph 2.4.2. More theoretical information on Life Cycle Assessments is presented in appendix VIII – B.

The main advantage of using LCA is the fairly complete coverage, which causes a fairly accurate estimate of environmental costs and burdens (Kumar et al., 2001; Fussler and James, 1996). Furthermore, LCA can be used as a decision support system (Heijungs, 1994). However, disadvantages of LCA are numerous. Mentioned in the literature are the necessity for a lot of assumptions and methodological choices (Dewulf, 2003; Kumar et al., 2001; Stevels, 2006; Fussler and James, 1996), the lack of good quality input data (Dewulf, 2003; Kumar et al., 2001), the discrepancy between the calculated potential and the expected environmental impact (Dewulf, 2003), and the amount of time and means needed (Dewulf, 2003; Kumar et al., 2001; Fussler and James, 1996). Jensen et al. (1997) asked practitioners to comment on the best ways of building and maintaining public confidence in LCA:

• The professionalism and training of those undertaking LCA work,
• Accepted standards and methodologies (weighting),
• Internal sensitivity analysis and data checks,
• Peer or critical review, including public questioning at seminars and conferences,
• Transparent reporting of processes and outcomes,
• Stakeholder dialogue,
• Verification,
• The data should be updated regularly,
• Ranges of uncertainty should be indicated,
• The date and source of any data should be clearly identified,
• Formats should be harmonized, wherever possible, and
• Particular attention should be paid to gathering essential infrastructure data relating, for example to energy, transport, and solid waste management.

Weighting environmental effects has a lot of opposition because of its subjectivity. However, a weighting always needs to be done (Van Soest et al., 1997; Stevels, 2006). It is important though to show the points of view supporting the weighting methods, to make it explicit, which allows for transparency in the decision-making process (Van Soest et al, 1997). The three most interesting weighting methods are shadow prices, distance-to-target and Eco-Indicator according to Van Soest et al. (1997). Shadow prices and distance-to-target are both meant for making decisions with a national reach whereas Eco-Indicator is meant for decisions concerning products. To choose the optimal weighting method, two decision-making processes are distinguished: national and international (often product level: from cradle to grave) (Van Soest et al., 1997).
The LCA can be simplified. The aim of simplifying LCA is to provide essentially the same results as a detailed LCA, but with a significant reduction in expenses and time used (Jensen et al., 1997). However, simplification presents a dilemma, since it is likely to affect the accuracy and reliability of the results of the LCA. Thus, the primary object of simplification is to identify the areas within the LCA that can be omitted or simplified without significantly compromising the overall result (Jensen et al., 1997). Proposed methods to simplify and significantly reduce the amount of resources required for LCA modelling are checklists, qualitative matrices, abridged LCA, and LCA streamlining, to a variety of other forms of approximate LCA (Sousa and Wallace, 2006). Simplification of LCA consists of three stages that are iteratively interlinked (Jensen et al., 1997):

- Screening: identifying those parts of the system (life cycle) or of the elementary flows that are either important or have data gaps,
- Simplifying: using the findings of the screening in order to focus further work on the important parts of the system or the elementary flows, and
- Assessing reliability: checking that simplifying does not significantly reduce the reliability of the overall result.

LCA could be used along with the Eco-compass, which is developed by Fussier and James (1996). Eco-compass is a technique for communicating LCA data and integrating them into business decision processes.

5.3.3 Conclusions

Benchmarking in this project is defined as ‘the art of finding out, in a perfectly legal and aboveboard way, how others do something better than you do-so you can imitate-and perhaps improve upon-their techniques’ (Drew, 1997). Philips executes internal, external and functional product benchmarking. External benchmarking is perceived as the most successful method (Drew, 1997). Reference products (benchmark partners) should neither be too similar nor too different to gain the best results. The environmental indicators used in the benchmark should be SMART (Specific, Measurable, Achievable, Relevant and Time bound).

LCA in this project is defined as ‘a method which allows the development of objective criteria and procedures for the assessment of the environmental impacts of products, based on the total Life Cycle of the product (from cradle to grave)’ (Klöpffer and Rippen, 1992). Philips uses detailed (SimaPro) and screening (EcoScan) LCA techniques. The Eco-Indicator 99 (EI99) that Philips uses seems a suitable measure since it provides transparency to the weighting of environmental themes and is meant for decisions concerning products. LCA’s can be simplified by identifying key denominators or data gaps, use these findings for simplification options and check the reliability of the results of the simplified process. Finally, the LCA results can be graphically communicated using the Eco-compass of Fussier and James (1996).
6 Results case study analyses

The development of the case studies is described first in this chapter. Hereafter, the analyses executed are explained and the results are presented. The results have led to the hypotheses, which are mentioned next. The last section describes the testing of the hypotheses, which resulted in several options for the redesign.

6.1 Development Case Study sample

The case study approach is shown in Figure 4-3. This section discusses the first six steps of this approach.

During several interviews it turned out that the benchmark process is less complicated than the LCA process. Moreover, simplifying LCA is possible (see paragraph 5.3.2). Therefore, the practice research started with the search for all LCA’s executed at Lighting (step 1). Only LCA’s for the Business Groups (BG) Lamps and Lighting Electronics were found.

The data turned out to be rather out-of-date. Another problem was that both EI95 and EI99 were used (EI99 is an update of EI95). These two methods are not comparable since they work with different weighting factors for the environmental themes. Therefore, the first thing to do was to retrieve the input from the old LCA’s and use these as input for new LCA’s. This updating of LCA’s secured the comparability of the LCA’s since they are all linked to the most up-to-date databases (i.e. using the most up-to-date formulas for emissions) and are all expressed in EI99 (step 2).

The data for the case studies were not totally complete, so additions needed to be found and assumptions needed to be made (step 3). Overviews of the data and the assumptions (step 4) have been verified by experts (step 5). A description of the case studies from the sample and the accompanying additions and assumptions can be found in appendix IX.

After the verification, a focus was necessary to be able to compare the results. Since most LCA’s were lamps, the focus has been put on the BG Lamps. However, some lamps cannot function without ballast. To make honest comparisons the Lamps and Lighting Electronics LCA’s needed to be combined in those cases.

All 30 lamp LCA’s are called sample case studies from this point onwards¹ (step 6). The data from the case study sample are summarized in appendix X.

The case studies were updated using EcoScan. Table 6-1 shows the factors that are included in the each phase in the updated LCA’s.

¹ There were originally 31 case studies available. However, in the discriminant analysis the predicted classification of one case study was wrong indifferent of which predictors are used. Therefore, this case study is removed from the sample. The case study removed is the CDM-TD. The abnormality could be explained by the use of the far too small ballast. Assuming this ballast the Eco-Indicator for the production phase is far too low, which influences the predictor for the Life Cycle score.
The life cycle of a lamp is illustrated in Figure 6-1. The pre-production and production of Figure 6-1 are combined into one phase in EcoScan. EcoScan makes use of a database, which includes Eco-Indicators for each material. These EI are calculated including the influence of the extraction and the pre-production if applicable. The distribution phase of Figure 6-1 is split in the packaging of the lamp and the transport in the update.

Figure 6-1 Outline approach LCA of a typical electrical light bulb (DQE, 2008)

The division of the different lamp technologies included in the case study sample can be seen in Figure 6-2. As can be seen the case study sample is a good representation of the total lamp population since the technologies are very diverse and cover most different technologies available.
6.2 Case study analyses

This subchapter describes the six analyses executed and presents the results (step 7). Each analysis will be handled in a different section.

6.2.1 Centre of gravity analysis

A centre of gravity analysis (analysis A) is used to calculate the contribution of each of the phases of the life cycle to the total environmental impact. The result is insight in the key denominating phases, which can be used to simplify LCA (see paragraph 5.3.3).

The centre of gravity analysis is executed on the 30 case studies from the case study sample. The average contribution and standard deviation percentages of the different phases on the total life cycle impact are shown in Table 6-2. A more detailed overview of the results of the centre of gravity analysis can be found in appendix XI - A.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Average percentage</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production phase</td>
<td>2.86%</td>
<td>2.58%</td>
</tr>
<tr>
<td>Use phase</td>
<td>97.15%</td>
<td>2.60%</td>
</tr>
<tr>
<td>Packaging phase</td>
<td>0.13%</td>
<td>0.14%</td>
</tr>
<tr>
<td>Transport phase</td>
<td>0.53%</td>
<td>1.07%</td>
</tr>
<tr>
<td>Disposal phase</td>
<td>-0.66%</td>
<td>0.71%</td>
</tr>
</tbody>
</table>

Table 6-2 Results centre of gravity analysis

All deviations are large compared to the average. This can be explained by differences in production processes, production locations, packaging materials and materials in the lamp (which implies different ways for disposal). However, the standard deviation for the use phase is relatively small. Per lamp technology the average percentage of the use phase grows with the increase of the lamp wattage. All use phase percentages are above 95% except those of the EcoClassic50. These lamps have a relatively high transport contribution since one part is sub-assembled in Jaden and the total lamp assembly takes place in China.
The disposal phase causes a negative influence on the total environmental life cycle impact, which means a positive influence on the total environmental impact since it lessens the total impact (e.g. by recycling of materials).

Literature and experts already stated that the use phase of lamps causes about 90% or more of the total life-cycle impact (see 5.2.1). The case study sample results confirm these statements, since the usage phase is responsible for the main part (97.15% on average) of the total environmental life cycle impact.

6.2.2 Analysis Life Cycle scores

The Life Cycle scores (EI99) of the case study sample have been thoroughly analysed in the search for simplification options (analysis B). The details of the results of the analyses of these subparagraphs can be found in appendix XI - B.

6.2.2.1 Multiple linear regression

A multiple linear regression analysis on the 30 case studies is used to find a predicting formula for the total Life Cycle score (dependent variable) that is a linear combination of the scores of the different phases (independent variables) (see Equation 6-1). All variables are expressed in millipoints (mPt).

\[
\text{TotalEI99(mPt)} = 12.290 + 0.712 \times \text{ProductionEI99(mPt)} + 1.000 \times \text{UseEI99(mPt)} + 1.251 \times \text{PackagingEI99(mPt)} + 0.935 \times \text{TransportEI99(mPt)}
\]

Equation 6-1 Estimation formula TotalEI99 based on multiple linear regression

To check the accurateness of the estimating formula, the R² is discussed. R² is a measure for the amount of the variability that is accounted for using an estimating formula. The R² of this formula is 1, which means 100% of the variability of the total EI99 is accounted for using Equation 6-1.

The relative importance of each independent variable can be understood when all variables are standardized (converted to values with a mean of 0 and a standard deviation of 1) (see Equation 6-2). As can be seen the use phase has the strongest influence on the total Life Cycle score, followed by the production phase. The influence of the transport phase is very small. The influence of the packaging phase is negligible.

\[
Z_{\text{TotalEI99}}(mPr) = 0.024 \times Z_{\text{ProductionEI99}}(mPr) + 0.976 \times Z_{\text{UseEI99}}(mPr) + 0.001 \times Z_{\text{TransportEI99}}(mPr)
\]

Equation 6-2 Estimation formula TotalEI99 with standardized variables

In the total Life Cycle score (TotalEI99) the disposal phase is included. However, most values calculated for this phase are calculated using an automatic disposal function in EcoScan, which calculates with ideal disposal scenarios for materials. Yet, in real life the disposal of lamps will not have such a big impact on the total environmental life cycle impact since users will throw away most lamps instead of recycle them. Therefore, the disposal phase is not included in this analysis as an independent variable.
6.2.2.2 Sensitivity analysis

A sensitivity analysis is used to search for the most influencing input parameters of each phase of the life cycle. The outcomes of the sensitivity analysis can be used to predict the different factors of Equation 6-1.

Production phase

The factor ProductionEI99 can be estimated based on the amount of glass and the amount of flu suspension (if present) used as can be seen in Equation 6-3. The $R^2$ of this formula is 0.933, which means 93.3% of the variance of the ProductionEI99 is accounted for using this formula.

$$ProductionEI99(mPt) = 188.416 - 104541.748 \times Flususpension(l) + 3.377 \times Glass(g)$$

Equation 6-3 Estimation ProductionEI99

The strength of each correlation is expressed in Equation 6-4. The strengths of the influences are about the same. However, the amount of flu suspension has a negative influence on the ProductionEI99 whereas the amount of glass has a positive influence.

$$Z_{ProductionEI99}(mPt) = -1.301 \times Z_{Flususpension}(l) + 1.708 \times Z_{Glass}(g)$$

Equation 6-4 Estimation ProductionEI99 with standardized variables

The comparison of the actual scores and the estimated scores of the 16 cases (y-axis), for which amounts of glass and flu suspension are present, is shown in Figure 6-3. The actual and estimated scores for each case study (x-axis) are shown in this figure. The deviations that can be seen are the part of the variance that is not accounted for $(1 - R^2)$ using this estimation, which is 6.7%.

![Predicted and actual ProductionEI99 scores](image)

Figure 6-3 Predicted and actual ProductionEI99 scores

Use phase

The factor UseEI99 can be calculated exactly following Equation 6-5. The lifetime50% is a standard measure for the lifetime. It represents the time that passes until 50% of the lamps fail during testing. The last factor of this equation is a value for the damage to the environment per
kilowatt-hour. This value is derived from the EcoScan database. When new emission and/or energy formulas are implemented this factor needs to be adjusted.

\[
UseEI99(mPt) = \text{Lifetime50\%}(h) \times \text{EnergyUsage}(kW) \times 22.4(mPt)
\]

Equation 6-5 Calculation UseEI99

**Packaging phase**

No sensitivity relations could be found for the packaging phase. Therefore, it is not possible to estimate the PackagingEI99. However, this is not a big issue since the relative importance of the packaging phase is zero (see Equation 6-2).

**Transport phase**

The factor TransportEI99 can be estimated based on the weight of the system (see Equation 6-6). The \( R^2 \) of this formula is 0.973, which means 97.3% of the variance of the TransportEI99 scores is accounted for. This \( R^2 \) is only dependent on one variable, i.e. there is no combination of variables that together determine the accurateness of the estimation. Therefore, the strength of the correlation is also 0.973.

\[
TransportEI99(mPt) = 11.829 + 0.073 \times \text{WeightSystem}(g)
\]

Equation 6-6 Estimation TransportEI99

Figure 6-4 is a scatter plot of the transport scores (y-axis) of the 30 cases in relation to the weight of the system (x-axis). Except for three outsiders (the EcoClassic50 lamps and the LED lamp) all dots are on a linear line, which is described by Equation 6-6.

![Figure 6-4 Relation of weight system with Transport EI99](image)

**6.2.3 Analysis Green Products versus non Green Products**

An independent-samples \( t \) test is used to evaluate the difference between the means of the values for the six product characteristics of Green Products and non Green Products (analysis C). There are 21 Green Products and 9 no Green Products in the case study sample. It is important to know whether there are significant differences between these groups to gain insight in the groups.
The characteristics under consideration are based on the Green Product definition (see paragraph 5.2).

- **Comparable Life Cycle score**
  Since comparisons should be possible the total Life Cycle score (EI99) needs to be divided by the amount of Lumenhours. The amount of Lumenhours is calculated by multiplying the amount of light output with the 50% lifetime of the lamp. This standardizes the Life Cycle scores.

- **Energy efficiency**
  The measure for energy efficiency that allows for comparisons is the energy efficacy expressed in Lumens per Watt.

- **Weight of the lamp**
  The weight of the lamp systems is analysed in two measures, the weight in grams and the weight divided by the amount of Lumenhours, to see which is more appropriate.

- **Hazardous substances**
  The hazardous substances are also analysed in two measures, one is indicated in milligrams of mercury and one in milligrams of mercury per Lumenhour.

The p-values for the six characteristics indicate the significance of the difference of the means of the two groups (see Table 6-3). If the p-value is smaller than or equal to 0.05, the difference between the two groups is significant (green p-values).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparable Life Cycle score (mPt / Lm*h)</td>
<td>0.006</td>
</tr>
<tr>
<td>Energy efficacy (Lm / W)</td>
<td>0.022</td>
</tr>
<tr>
<td>System weight (g)</td>
<td>0.548</td>
</tr>
<tr>
<td>Hazardous substances (mg)</td>
<td>0.183</td>
</tr>
<tr>
<td>System weight per Lumenhour (g / Lm*h)</td>
<td>0.019</td>
</tr>
<tr>
<td>Hazardous substances per Lumenhour mg / Lm*h)</td>
<td>0.329</td>
</tr>
</tbody>
</table>

Table 6-3 Significance difference means Green Products and no Green Products case study sample

The means of the comparable Life Cycle score and energy efficacy are significantly different for Green Products and non-Green Products. The means of the weight of the system and the amount of hazardous substances are not significantly different. However, when correcting the lighting systems for the lifetime of the lamp, i.e., looking at the system weight per Lumenhour, a significant difference can be found. This is not true for hazardous substances per Lumenhour. Details on the results of the independent-samples t tests can be found in appendix XI–C.

Box plots show the differences in the values for the parameters for Green Products and non-Green Products (see Figure 6-5). The x-axis shows the two groups and the y-axis represents the value for the specific characteristic. The upper and lower end of each box represent the highest and lowest value respectively (except in case of extreme values, e.g., at the system weight box plot). The line in the middle of the box is the median (the number separating the higher half of a sample from the lower half, i.e., the middle value if all the observations are arranged from lowest value to highest value). The box includes 25% of the values above the median and 25% of the values below the median.
The boxes in the box plots do not overlap for the characteristics with significant differences between Green Product and non Green Products, which means that at least 75% of the values for one group score higher than 75% of the values for the other group.

Figure 6-5 Box plots differences means Green Products and no Green Products case study sample
6.2.4 Discriminant analysis

Discriminant analysis (analysis D) is used to classify products into groups (Green Products or non Green Products) based on linear combinations of values for product characteristics. This analysis is executed to check whether it is statistically correct to base the Green Product classification on the four characteristics used in the Green Product definition (see paragraph 5.2). Moreover, the possibility of predicting the Green Product classification for all products based on these characteristics is checked. The details of this analysis can be found in appendix XI – D.

Since two characteristics are expressed in two unities (weight and hazardous substances), there are four parameters to include as predictors of the classification in the test. Two combinations of predictors resulted in a correctly predicted classification score of 100%, with a Kappa index (a measure that is corrected for chance agreement) of 1.000 (i.e. perfect predictions).

The difference between the two sets of predictors is the way of expressing the weight of the system (grams versus uses grams per Lumenhour). A choice needed to be made. There is a significant difference in the means of the system weight per Lumenhour (and not of the system weight) between Green Products and no Green Products (see paragraph 6.2.3). Therefore, the weight per Lumenhour is used as a predictor.

Eliminating one or more of these predictors does not improve the accuracy of the estimation. Therefore, the following predictors can be seen as most significant to determine the Green Product classification:

- Weight: weight system (g / Lm*h)
- Energy efficiency: energy efficacy (Lm/W)
- Hazardous substances: mercury (mg)
- Life Cycle score: Eco-Indicator 99 (mPt / Lm*h)

Hence, looking at the predictors, it is statistically correct to base the Green Product classification on the four characteristics from the definition.

The discriminant analysis resulted in a single discriminant function that can serve as a basis for predicting the Green Product classification. According to the results, 94.3% of the variability of the scores of this function is accounted for by differences among the two classification possibilities (Green Product or non Green Product).

The classification results of the discriminant analysis allow determining how well group membership is predicted using a classification function. The original classification indicates how well the discriminant function predicts Green Product classification in the sample. Of the case study sample 30 cases are classified correctly (100%). The cross-validated classification is generated by the leave-one-out method. Again 100% of the cases are classified correctly. The Kappa index for these four parameters is 1.000, which means the predictions are perfect.

The standardized canonical discriminant function coefficients are the base for the formula that can be used to predict Green Product classification (see Equation 6-7).
The outcome of this discriminant formula is the base for a Green product classification. The average outcome of Green products is -1.97 (with a standard deviation of 0.32) and the average outcome for non Green Products is 4.72 (with a standard deviation of 1.75). This means that the 95% reliability intervals (average plus and minus twice the standard deviation) of Green products and non Green Products do not overlap.

A scatter plot of the outcomes of the discriminant function (y-axis) for the case study sample (x-axis) is shown in Figure 6-6. When applying the discriminant function on other products, the outcome has to be matched with one of the reliability intervals and can then be classified accordingly.

### 6.2.5 Relation parameters

The different characteristics might influence each other. Therefore, it is very relevant to know the relations between them (analysis E). Some characteristics are mutually dependent. Expected relations are:

- When the energy efficiency is increased, the Life Cycle score will decrease.
- When the amount of hazardous substances is decreased, the Life Cycle score will decrease.
- When the amount of hazardous substances is decreased, the energy efficiency might decrease.

Figure 6-7 is constructed using curve estimations. It provides insight in the relations between the characteristics by showing the scatter plots per combination of characteristics.
In Figure 6-7 each box shows the scatter plot of the characteristic on the left side (y-axis) and the characteristic on the bottom (x-axis) of that box.

The relations from Figure 6-7 have been analysed. The only significant relation found is the power relation between energy efficacy and the comparable Life Cycle score (Total_LC_score_Lmh). The R² of this relation is 0.999 meaning that 99.9% of the variance in the comparable Life Cycle score is accounted for by this relation. The formula underlying to this relation is Equation 6-8. Details on this analysis are shown in appendix XI – E.

\[
\text{TotalComparableEI99}(mPt/Lm*t) = 0.023 \times \text{EnergyEfficacy}(Lm/Wh)^{1.004}
\]

Equation 6-8 Power relation Energy Efficacy and Total Comparable EI99

Each dot in Figure 6-8 shows the value of the comparable Life Cycle score (y-axis) for the energy efficiency value (x-axis) for all case studies. The line represents Equation 6-8.
6.2.6 Analysis technology clusters

To analyse the possibilities for classifying technology-based clusters as Green or not based on an internal application benchmark (see 5.3.1), a selection of the case study sample has been made. In the case study sample six technology-based clusters (including more than one product) with the application home and offices are distinguished. Therefore, 20 case studies in six technology-based clusters have been selected for this analysis.

To test whether the means of the values for the six product characteristics of the clusters are significantly different for the characteristics independent-samples t tests have been executed between all combinations of clusters. The characteristics for which significant differences in the means of two technology-based clusters could be found are summarized in Table 6-4 (the meaning of the numbers is explained in Table 6-5). The tables with the p-values can be found in appendix XI - F.

<table>
<thead>
<tr>
<th>Number</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Comparable Life Cycle score (mPt / Lm*h)</td>
</tr>
<tr>
<td>2</td>
<td>Energy efficacy (Lm / W)</td>
</tr>
<tr>
<td>3</td>
<td>System weight (g)</td>
</tr>
<tr>
<td>4</td>
<td>Hazardous substances (mg)</td>
</tr>
<tr>
<td>5</td>
<td>System weight per Lumenhour (g / Lm*h)</td>
</tr>
<tr>
<td>6</td>
<td>Hazardous substances per Lumenhour mg / Lm*h)</td>
</tr>
</tbody>
</table>

Table 6-5 Legend table 6-4

Beneath, box plots show the differences in the values for the parameters for each cluster (see Figure 6-9). These box plots give insight in the direction of the differences.

These analyses show that there are significant differences (no overlap of the boxes) between the energy saving technologies (i.e. TLD, PL-C, PLE-C, and TL5) and the traditional technologies (i.e. GLS and EcoClassic50) for the comparable Life Cycle score, energy efficiency, hazardous substances, weight per Lumenhour, and hazardous substances per Lumenhour.

---

5 In case two case studies are very similar, e.g. a professional and a consumer variant, only one is included in this test to prevent from disproportional comparisons.
6.2.7 Conclusions

Six analyses have been executed in the search for options for the simplification of LCA. The conclusions will be summarized here.

- A centre of gravity analysis provided insight in the key denominators of the total Life Cycle score. The case study sample results confirm literature and expert statements that the usage phase is responsible for the main part (97.15% on average) of the total environmental life cycle impact.
The Life Cycle scores are further investigated by a multiple linear regression analysis and a sensitivity analysis. In the sensitivity analysis, the amount of glass and flu suspension turned out to be estimators for the production phase. The use phase can be calculated when the power usage and the 50% lifetime are known. The transport phase is dependent on the weight of the system. No predictor could be found for the packaging phase. The total Life Cycle score can be estimated using the predicted values for each phase (multiple linear regression).

The differences between Green Products and no Green Products have been investigated. Significant differences have been found for the comparable Life Cycle score, energy efficiency, and the system weight per Lumenhour.

A method for classifying products, discriminant analysis, is tested. A discriminant function is developed. The outcome of this function can be matched with one of the 95% reliability intervals of Green Products and non Green Products and estimate the Green Product classification this way.

The relations between the parameters have been reviewed. One significant power relation is found between energy efficacy and the comparable Life Cycle score.

Finally, technology-based clusters have been analyzed. Significant differences between the Green and not Green technologies could be seen for all characteristics except for system weight.

These conclusions only hold for the case study sample. Since the improvements in the Green Product classification process need to be applicable for the total product portfolio of Philips Lighting, the conclusions are seen as hypotheses (step 8). These have to be tested on a larger sample that is representative for the whole product portfolio.

- **H1**: The total Life Cycle score can be estimated using an add-up percentage to the use phase (based on results centre of gravity analysis in paragraph 6.2.1).
- **H2**: The total Life Cycle score can be estimated using multiple linear regression, i.e. Equation 6-1 through Equation 6-6 (based on results sensitivity analysis in paragraph 6.2.2).
- **H3**: Green Product classification can be estimated based on the discriminant function, i.e. Equation 6-7, using the parameters weight system/Lm*h, energy efficacy (Lm/WW), mg mercury, and EI99/Lm*h (based on results analysis Green Products and no Green products and discriminant analysis in paragraphs 6.2.3 and 6.2.4).
- **H4**: The comparable life cycle score (EI99/Lm*h) can be estimated using the Power relation with energy efficacy (Lm/WW), i.e. Equation 6-8 (based on results analysis parameters in paragraph 6.2.5).
- **H5**: Green Product classification can be done using technology-based clusters (based on results analysis technology-based clusters in paragraph 6.2.6).

### 6.3 Hypotheses testing

The five hypotheses are tested using different methods (step 9). A sample that is representative for the whole portfolio is used whenever possible. However, this is not possible for the testing of hypotheses 1, 2 and 4 since the Life Cycle score is not known for more products than those in the case study sample. Therefore, abnormality and sanity checks are used for the testing of these hypotheses. These tests are described in separate subchapters. The section ends with the conclusions that can be drawn.
6.3.1 Representative sample

To be able to make generalizations for the total Lamps product portfolio a bigger sample is needed. From the Prisma product database product details for 296 consumer and 642 professional products have been collected and put in a database together with the 30 case study sample cases. The division of the samples compared to the total population (Lamp's product portfolio) can be seen in Table 6-6.

<table>
<thead>
<tr>
<th>Portfolio Lamps (population)</th>
<th>Case study sample</th>
<th>Representative sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>Amount</td>
<td>Percentage</td>
</tr>
<tr>
<td>Incandescent (GLS)</td>
<td>48.0%</td>
<td>3425</td>
</tr>
<tr>
<td>Halogen</td>
<td>14.5%</td>
<td>1035</td>
</tr>
<tr>
<td>Compact fluorescent non integrated (CFL-NI)</td>
<td>3.0%</td>
<td>211</td>
</tr>
<tr>
<td>Compact fluorescent integrated (CFL-I)</td>
<td>13.0%</td>
<td>930</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>9.3%</td>
<td>666</td>
</tr>
<tr>
<td>Compact HID</td>
<td>1.7%</td>
<td>122</td>
</tr>
<tr>
<td>HID</td>
<td>2.6%</td>
<td>189</td>
</tr>
<tr>
<td>LED</td>
<td>5.6%</td>
<td>401</td>
</tr>
<tr>
<td>Others (e.g. traffic lights)</td>
<td>2.2%</td>
<td>154</td>
</tr>
</tbody>
</table>

Table 6-6 Division products samples and population

Although the percentages are not equal, the order of greatest to smallest cluster is about the same. Therefore, the sample is representative for the total population. The representative sample is instinctive, since each wattage of each (sub)technology that offers the characteristics weight, Lumen output, 50% lifetime and amount of mercury in Prisma is represented. The sample size is 968 (sum of case study and representative sample products) on a population of 7169, which means generalizations of the rejection or accepting of the hypotheses can be made with 99% confidentiality and an error of maximum 4% (909 products are needed for these numbers, for calculations see appendix XII – A). This representative sample is used to test hypotheses 3 and 5.

To gain insight, it is checked again whether there are significant differences in the means of the values for the six characteristics between Green Products and non Green Products using the independent-samples t test before checking the hypotheses. There are 231 Green Products and 737 non Green Products in the representative sample. Table 6-7 shows the p-values for the differences of the means.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparable Life Cycle score (mPt / Lm*h)</td>
<td>0.000</td>
</tr>
<tr>
<td>Energy efficacy (Lm / W)</td>
<td>0.000</td>
</tr>
<tr>
<td>System weight (g)</td>
<td>0.035</td>
</tr>
<tr>
<td>Hazardous substances (mg)</td>
<td>0.000</td>
</tr>
<tr>
<td>System weight per Lumenhour (g / Lm*h)</td>
<td>0.000</td>
</tr>
<tr>
<td>Hazardous substances per Lumenhour mg / Lm*h)</td>
<td>0.084</td>
</tr>
</tbody>
</table>

Table 6-7 Significance difference means Green Products and no Green Products representative sample
The differences in the means of Green Products and non Green Products have increased compared to the case study sample as did the significances. Only for the characteristic hazardous substances per Lumenhour there is not a significant difference in the means of Green Products and non Green Products. Figure 6-10 provides insight in the differences by the use of box plots.

The boxes in the box plots do not overlap for the characteristics with significant differences in means between Green Product and non Green Products.

Figure 6-10 Box plots differences means Green Products and no Green Products representative sample
To test hypothesis 3 the discriminant formula has been applied to the representative sample. Of the 968 products 149 were classified wrong (15.4%). No satisfying results were gained when executing a new discriminant analysis on the representative sample (see appendix XII – B).

Dividing the products in technology-based clusters is the basis for testing hypothesis 5. The division is now based on the division in Prisma. The results for the p-values can be found in appendix XII – C. Most means are significantly different. The means that are not significantly different are summarized in Table 6-8.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Not significantly different means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparable Life Cycle score⁶</td>
<td>CFL-I - Fluorescent</td>
</tr>
<tr>
<td></td>
<td>CFL-NI - Compact HID</td>
</tr>
<tr>
<td></td>
<td>Fluorescent - Compact HID</td>
</tr>
<tr>
<td>Energy efficacy</td>
<td>Incandescent - LED</td>
</tr>
<tr>
<td></td>
<td>CFL-NI - Fluorescent</td>
</tr>
<tr>
<td></td>
<td>CFL-NI - Compact HID</td>
</tr>
<tr>
<td></td>
<td>Fluorescent - Compact HID</td>
</tr>
<tr>
<td>Weight of the system</td>
<td>Fluorescent - Compact HID</td>
</tr>
<tr>
<td>Hazardous substances</td>
<td>Incandescent - Halogen</td>
</tr>
<tr>
<td></td>
<td>Incandescent - LED</td>
</tr>
<tr>
<td></td>
<td>Halogen - LED</td>
</tr>
<tr>
<td>System weight per Lumenhour</td>
<td>Halogen - CFL-I</td>
</tr>
<tr>
<td></td>
<td>Halogen - Compact HID</td>
</tr>
<tr>
<td></td>
<td>Halogen - HID</td>
</tr>
<tr>
<td></td>
<td>CFL-I - Fluorescent</td>
</tr>
<tr>
<td></td>
<td>CFL-NI - Compact HID</td>
</tr>
<tr>
<td></td>
<td>CFL-NI - HID</td>
</tr>
<tr>
<td></td>
<td>Compact HID - HID</td>
</tr>
<tr>
<td>Hazardous substances per Lumenhour</td>
<td>Incandescent - Halogen</td>
</tr>
<tr>
<td></td>
<td>Incandescent - LED</td>
</tr>
<tr>
<td></td>
<td>Halogen - LED</td>
</tr>
<tr>
<td></td>
<td>CFL-I - Fluorescent</td>
</tr>
<tr>
<td></td>
<td>CFL-NI - Compact HID</td>
</tr>
</tbody>
</table>

Table 6-8 Technology-based clusters with no significant differences in means

When comparing clusters it is better to use system weight and hazardous substances without dividing by the amount of Lumenhours. The hazardous substance couples in Table 6-8 make sense since these technologies do not include mercury in their lamps. Six out of the eight technology-based clusters or more have means that are not significantly different from another cluster. Figure 6-11 provides insight in the direction of the differences.

Based on these box plots it can be said that there are significant differences (no overlap of the boxes) between most new technologies (i.e. CFL-I, CFL-NI, Fluorescent, compact HID and HID) and the traditional technologies (i.e. Incandescent and EcoClassic50) for the comparable Life Cycle score, energy efficiency, weight of the system, hazardous substances, and hazardous substances per Lumenhour. However, for the newest technology (LED) this conclusion does not hold.

⁶ The comparable Life Cycle score is estimated using the hypothesized Power relation with energy efficiency.
6.3.2 Abnormality test

In the abnormality test the estimations for the comparable Life Cycle score based on the hypotheses 1, 2 and 4 are compared to the actual (EcoScan) values of the comparable Life Cycle score. This comparison enables the evaluation of the abnormalities of the estimations. The results per case study are shown in appendix XII – D. The average values for the abnormality of each estimation method are summarized in Table 6-9.
Looking at the average abnormality all three hypotheses score well. However, the standard deviation of the estimation of hypothesis 2 is rather big compared to the other two.

### 6.3.3 Sanity check

The abnormality test is executed in comparison with the EcoScan values. Since the EcoScan LCA is a simplification of the detailed LCA from SimaPro, a sanity check with the original SimaPro values has been executed when possible (i.e. when a SimaPro LCA is available). The Eco-Indicator outcomes of SimaPro and EcoScan are compared first (see Table 6-10).

Table 6-9 Summary results abnormality test

<table>
<thead>
<tr>
<th></th>
<th>Add-up percentage (H1)</th>
<th>Multiple linear regression (H2)</th>
<th>Power relation (H4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average abnormality</td>
<td>-0.07%</td>
<td>1.07%</td>
<td>-1.78%</td>
</tr>
<tr>
<td>Standard deviation abnormality</td>
<td>2.67%</td>
<td>4.95%</td>
<td>2.61%</td>
</tr>
<tr>
<td>95% reliability interval</td>
<td>-5.40% - 5.25%</td>
<td>-8.83% - 10.97%</td>
<td>-6.99% - 3.44%</td>
</tr>
</tbody>
</table>

Table 6-10 Differences SimaPro – EcoScan

<table>
<thead>
<tr>
<th>Difference SimaPro – EcoScan</th>
<th>Softone 40W</th>
<th>Softone 60W</th>
<th>EcoClassic50 20W</th>
<th>EcoClassic50 30W</th>
<th>MASTER TL5 HE 28W</th>
</tr>
</thead>
<tbody>
<tr>
<td>EcoScan</td>
<td>-6.1%</td>
<td>-5.8%</td>
<td>-3.3%</td>
<td>-5.3%</td>
<td>-6.1%</td>
</tr>
<tr>
<td>EcoScan EXCL. DISPOSAL</td>
<td>-5.3%</td>
<td>-4.5%</td>
<td>-2.1%</td>
<td>-4.0%</td>
<td>-5.8%</td>
</tr>
</tbody>
</table>

The differences in the outcomes can be explained. The programs use different formulas for the calculation of Eco-Indicator, e.g. when using the same inputs for the use phase the outcomes are still 5-6% lower when using EcoScan. Furthermore, some input for the production phases are not available in the EcoScan database. The other differences exist because of different assumptions, e.g. for packaging and transport. Since the disposal phase is not available for the SimaPro LCA’s, the second row presents the abnormalities leaving out the disposal phase in the EcoScan LCA’s as well.

Table 6-11 gives the overview of the comparison with as well EcoScan (inclusive disposal) as SimaPro.

Table 6-11 Differences SimaPro – EcoScan

<table>
<thead>
<tr>
<th>EcoScan</th>
<th>Add-up percentage (H1)</th>
<th>Multiple linear regression (H2)</th>
<th>Power relation (H4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softone 40W</td>
<td>- 1.6%</td>
<td>- 18.8%</td>
<td>- 0.6%</td>
</tr>
<tr>
<td>Softone 60W</td>
<td>- 1.9%</td>
<td>- 13.6%</td>
<td>- 0.8%</td>
</tr>
<tr>
<td>EcoClassic50 20W</td>
<td>-8.7%</td>
<td>- 2.4%</td>
<td>- 9.8%</td>
</tr>
<tr>
<td>EcoClassic50 30W</td>
<td>-5.6%</td>
<td>- 1.0%</td>
<td>- 6.8%</td>
</tr>
<tr>
<td>MASTER TL5 HE 28W</td>
<td>-1.2%</td>
<td>- 0.2%</td>
<td>- 0.7%</td>
</tr>
<tr>
<td>Average</td>
<td>-1.9%</td>
<td>7.1%</td>
<td>-3.2%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>4.9%</td>
<td>8.5%</td>
<td>4.8%</td>
</tr>
</tbody>
</table>
The results in Table 6-11 show a more negative picture than when looking at the total case study sample as can be seen from the average and standard deviations of the abnormalities with the EcoScan calculations. Looking at the results of the sanity test, the average abnormality of the multiple linear regression estimation is best, but the standard deviations of the other two estimations are much better.

### 6.3.4 Conclusions

Three methods have been used to test the hypotheses. Whenever possible, a representative sample has been used. Next to this sample, an abnormality and sanity test have been executed to verify the accurateness of the estimations. These testing methods provided insight in the acceptation or rejection of the hypotheses, which will be described here (step 10).

- Based on the outcomes of the abnormality test hypotheses 1, 2 and 4 cannot be rejected. All averages and standard deviations of the abnormalities are smaller than 5%.
- Looking at the results of the sanity check, hypothesis 2 scores best. However, the outcomes of hypotheses 1 and 4 are more constant (smaller standard deviation), which is favourable. Therefore, hypotheses 1, 2 and 4 can still not be rejected.
- Hypothesis 3 however, cannot be accepted after testing with the representative sample. As well the discriminant function from the case study sample as trying to find new discriminant function(s) for the representative sample did not give satisfying results.
- The test with the representative sample is much more valuable than the abnormality and sanity tests since these last two have been executed on the same sample that was used for setting the hypotheses. However, since it is not possible to do more valuable testing the hypotheses 1, 2 and 4 are accepted based on the results of these tests.
- Hypothesis 5 cannot be accepted or rejected. Too many differences in means are not significant to be able to draw cluster-based conclusions. The acceptation or rejection of hypothesis 5 depends on which clusters are to be compared. Since cluster comparison is really favourable for Philips and it is possible between several clusters, it will be considered an option for redesign.

Hypotheses 1, 2, 4 and 5 could not be rejected by the analyses executed and are therefore considered options for the simplification of the Green Products classification process:

- The total Life Cycle score can be estimated using an add-up percentage to the use phase,
- The total Life Cycle score can be estimated using multiple linear regression,
- The comparable life cycle score can be estimated using the power relation with energy efficacy, and
- Green Product classification can be done using technology-based clusters.
Chapter 6 provided four options for the simplification of the Green Product classification process. This chapter first describes the design criteria. Hereafter, the choice between the four options is underpinned. The redesign of the Green product classification process is presented next. A reflection on the redesign is given in the next section. Finally, the last section is a discussion on the results.

7.1 Design criteria

The tool that is going to be designed needs to fulfil several criteria. These will be defined in this subchapter. The tool under consideration needs to measure the performance of products as the base for the Green Product classification. Therefore, it is actually a performance measurement system (PMS). Requirements found in literature on PMS are described first. Hereafter, the relevant aspects specified for this project are discussed. The section ends with a summary of the design requirements.

7.1.1 Performance Measurement Systems

Several definitions of PMS exist in the literature. In this project, performance measurement is defined as 'the periodic measurement of progress towards explicit short and long-run objectives and the reporting of the results to decision makers in order to attempt to improve program performance' (Cook et al., 1995). A PMS is the system (software, databases and procedures) to execute performance measurement (Lohman et al., 2004). The elements of a PMS are a set of performance indicators, procedures for periodic data gathering, and the group of organizational actors they relate to. A more theoretical background on PMS can be found in appendix XIII – A.

In designing a PMS, several prerequisites have to be defined (Verkerk, 1998):

1. A defined process or product: what must be measured?
2. Defined objectives: what is viewed as correct and incorrect performance?
3. Tools to measure: how must the measurement take place?
4. Defined performance indicators: how must the measurement be transformed into information?

Once these requirements are fulfilled, real use of the information can take place by judging the output of the measurement against quantitative norms and limits of control and subsequent problems can be analyzed using knowledge and experience. Verkerk (1998) summarizes seven requirements from literature that PMS has to fulfil:

- Validity: properly defined performance indicators and underlying data and currency of those data,
- Completeness: measurement must exactly reflect the definition of the performance indicator,
- Comparability: ability to compare measurement through time and with other units; this causes requirements for dimensions of the indicators and moments of measurement,
- Accuracy: measurement must be precise enough and in case of samples the output of the measurement must be representative,
• Usage: the decision maker must experience the output of the measurement as valuable input for decision making and communication,
• Compatibility: fit between performance measurement system and information system, and
• Profitability: costs of performance measurement must be lower than benefits.

A performance indicator is a formula or rule that enables quantification of performance. Quantification is the essence of measurement because it adds figures to performance through a set of prescribed indicators (De Haas and Kleingeld, 1999). A performance indicator should be clearly defined. Furthermore, there should be clear norms for the measurement to judge performance (Verkerk, 1998). The key issue in designing measures of performance is that they have to be matched to the organizational context (Neely et al., 1997). Neely et al. (1997) suggest performance indicators should be simple to understand, have visual impact, focus on improvement rather than variance, and are visible to all. The design of a performance measure is a process. The performance measure record sheet (see appendix XIII – B) provides a structure to support this process as it seeks to specify what a good performance measure constitutes (Neely et al., 1997). The framework ensures that the measures are clearly defined and based on an explicitly defined formula and source of data.

Different perspectives on what a product is and the purpose of the classification lead to distinct classification systems. Sousa and Wallace (2006) mention environmentally conscious product design as a fifth perspective next to the known four (marketing, organizations, engineering design and operations management). Some organizations have added social and environmental dimensions to their Balanced Score Card (BSC, the most important PMS according to Jiménez-Zarco et al., 2006) (Chanhall and Langfield-Smith, 2007). Performance is a term often used in relation to benchmarking. Therefore, performance measurement systems may include benchmarking (Chanhall and Langfield-Smith, 2007).

7.1.2 Description requirements tool

Before the design of this performance measurement tool can be started, the application of the tool needs to be defined. The application of the tool is classifying products that just come out of the innovation funnel (see Figure 2-2). These newly developed products are very important to classify as Green or not since they are prominent in the marketing activities. To be able to market a product as Green one should know whether the new product fulfils the first requirement of answering to the definition of Green products. However, it should also be able to use the tool for the (checking of the) classification of products that are already in the product portfolio.

In designing a performance measurement system several prerequisites need to be decided (Verkerk, 1998). Firstly, the process must be defined. The focus of this project is the objective classification of products (making justifiable Green claims) following the Philips (high level) definition of Green Products, using the Lighting conditions. In other words, the scope of this project is the part of the process from the status Candidate Product until the status Green Product / Green Sales (see Figure 2-3).

Secondly, the distinction between correct and incorrect performance needs to be made. To be classified as a Green Product (‘correct performance’) the Life Cycle score should be better and either a 10% improvement in energy efficiency combined with at least equal hazardous substances or a 10% improvement in hazardous substances combines with at least an equal
energy efficiency should be gained. In case these conditions are not fulfilled it is seen as 'incorrect performance' (not a Green Product).

Thirdly, a set of performance indicators needs to be developed that measure the performance (De Haas and Kleingeld, 1999). There are three parameters that are determinative for the Lighting Green Product classification, namely the life cycle score, the energy efficiency and the amount of hazardous substances. However, the guidelines state a potential Green Product needs to be evaluated on at least energy efficiency, hazardous substances and weight. Therefore, four parameters will serve as performance parameters in the redesign of the tool:

- Energy efficiency (Lm/W),
- Hazardous Substances (mg mercury),
- Weight (g), and
- Life Cycle score (EI99/Lm*h).

Fourthly, the way of transforming measurements into information needs to be defined. The required values to be able to calculate the scores of the performance indicators serve as input for the tool, e.g. luminous flux and power. Hereafter, the tool processes the input into measures for the performance indicators and produces the needed information (either a Green Product classification or not a Green Product classification).

The procedures for the gathering of data (including responsibilities of persons) need to be set up next (De Haas and Kleingeld, 1999). Standard procedures are set up after the tool has been developed. It is important to set guidelines for who has to do what, when, why, and how. Lastly, it is important to explain where the measurements should be gathered as these serve as the input for the tool.

Finally, the output of the measurement can be judged against norms (Verkerk, 1998). In this performance measurement tool a product’s scores on the performance indicators are judged by comparing them to the scores of another product (benchmarking). Therefore, the norm is the reference product. This tool performs a combination of process and product benchmarking, since the calculation of the Life Cycle score involves information of processes next to product details. The reference product should neither be too similar nor too distinct (see paragraph 5.3.1). Therefore, the tool will make use of functional benchmarking using the youngest preceding technology for the specific application as the norm.

Some other factors are under consideration in the design of the tool as well, such as the option of the clustering of products and the tolerance permitted in the outcomes. Firstly, since the tool will compare different lighting technologies (functional benchmarking), it could be possible to cluster products according to the technologies behind the products. However, this option needs further investigation (hypothesis 5). Secondly, it is desirable to have no fault margin in the outcomes. However, since whole clusters will be classified, some error might arise. The challenge is to find the right balance between accuracy and simplification. The values for energy efficiency, hazardous substances and weight can be measured very exactly. However, the Life Cycle score might be a problem. Therefore, an abnormality of 5% is permitted for this performance indicator.

There are some desired characteristics of the tool. The best moment of measuring is when a new cluster is developed. This means after a new technology is developed, which is seen as a radical innovation. Incremental innovations (improvement of a technology within a cluster) are
out of the scope of this tool since it occurs less often that 10% improvements are gained with
the improvement of an existing technology. New technologies should be compared to the
youngest preceding technology for the same application. The tool should be designed according
to Philips’ brand promise Sense and Simplicity. During interviews a fill-in form in Excel (like the
benchmark application form) is observed to be easy to use. The four input parameters should
lead to one of the two output possibilities: a Green Product or not a Green Product.

7.1.3 Summary
Next to the criteria mentioned in paragraph 3.3.2, interviews and literature pointed out some
more design criteria. Summarizing, the design of the tool should fulfil the following criteria:

- The tool should be designed for the long term,
- The norms (the reference product scenario) are set for the middle long term, as there
  might be a need for adjustments,
- The tool needs to be applicable for products for both businesses and end-consumers,
- The data should be available and easily accessible since an independent external verification
  should be possible,
- The tool should be described as a system (software, databases and procedures) to execute
  performance measurement (PMS),
- The performance indicators should be clearly defined (SMART),
- The tool should enable Life Cycle thinking,
- The tool should be able to classify products that just come out of the innovation funnel,
- The tool should be able to distinguish between correct and incorrect performance,
- The tool should be based on four performance measurement parameters,
- The output of the tool should be a Green product Classification or not,
- The tool should execute a functional benchmark,
- The tool should have 5% abnormality at most,
- The tool should be Sensible and Simple, and
- The tool should be easy to experience, designed around you and advanced.

7.2 Choice for redesign
With the options for the redesign and the design criteria known, a decision needed to be made.
The choice for one of the redesign options is based on the compliance with the design criteria,
the accompanying risks, and the user preferences. Each option for redesign is judged on each
decision criterion. The product that is the best option on the specific coterie receives four
points and the worst option receives one point (see Table 7-1).

<table>
<thead>
<tr>
<th>Add-up percentage</th>
<th>Compliance with the design criteria</th>
<th>Accompanying risks</th>
<th>User preferences</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple linear regression</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Power relation</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Technology-based clusters</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 7-1 Matrix redesign options
The multiple linear regression has a large standard deviation (see Table 6-9). Therefore, the 95% reliability interval shows abnormalities that are bigger than the 5% stated in the design criteria. This makes it the worst option from this point of view. The technology-based clusters offer for comparison but not all differences in means are significant. Also, when looking at the box plots (see Figure 6-9), overlap can be seen. Therefore, this option is second worst. An add-up percentage could be thought off for as well the add-up percentage as the power relation because of the small standard deviation. Since the power relation shows the biggest abnormalities in the sanity test, this option scores lower than the add-up percentage.

The technology-based cluster hypothesis could not be rejected but also not be accepted. This means using this hypothesis for the redesign includes a big risk. Therefore, this option scores worst. The multiple linear regression involves an estimation of the production phase ($R^2=0.933$) and an estimation of the transport ($R^2=0.973$) phase, which together with the use phase come to the total Life Cycle score. Each estimation has its own risks and fault margins. Therefore, the risks of this total estimation are bigger than of the other two options. Moreover, not all lamps have flu suspension inside, which means the estimation cannot be executed. The add-up percentage for a new technology can be significantly different. The trend is that lamps use less and less energy during use, so the percentage of use should become smaller and smaller. This motion causes a risk for the correctness of the estimation. Therefore, the power relation receives the higher score.

Interviews with the future owner and other stakeholders showed that technology-based clusters would be the most favourable solution. Therefore, this option receives four points. The multiple linear regression analysis requires more inputs while it is not more accurate, so it is given one point. The add-up percentage is less favourable than the power relation since it does not take the trend of lamps becoming more energy efficient into account, which makes it more difficult to explain the correctness of the estimation to customers in the future.

Adding up all the scores leads to the conclusion that the power relation has gained the highest scores. Therefore, this option is used in the redesign. The average abnormality of the power relation with actual EcoScan values is $-1.78\%$ and the 95% reliability interval is $-6.99\%$ to $3.44\%$. This is a bit more than the required 5%. The sanity check showed detailed SimaPro LCA’s generally result in higher scores than EcoScan LCA’s, which means an even larger abnormality. Therefore, an adjustment to the power formula should be made, i.e. an add-up percentage of $1.78\%$ to the power relation should be included to move the average abnormality to 0% and the 95% reliability interval to $-5.21\%$ - $5.22\%$.

### 7.3 Redesign

The redesigned Green Product classification process is a simplification of the scope part of the existing Green Product classification process (see Figure 7-1). The redesign has integrated the two processes (GFA Environmental Benchmark and Life Cycle approach) into one performance measurement process. This new process and the accompanying tool are presented in this section.

In the redesign, functional process and product benchmarking is used as performance measurement. The execution of benchmarking can be decomposed into five steps (Drew, 1997):

1. The object of the study is a new technology (radical innovation). The benchmarking partner is a preceding functional comparable product.
2. The collection of data is not necessary for internal benchmarking since the data of own products are in the developed and linked database. The data for new or competitor products can be found very easily since only basic characteristics of products serve as input.

3. Excel executes the analysis after filling in the products to be compared.

4. The next step is deciding whether it is a Green Product or not, which is also done by Excel. However, the decision whether a product should be branded as Green is not included in this tool since that is out of the scope of this project.

5. The Green Product classification should be communicated internally. When it becomes a Green branded Product, the classification needs to be communicated externally (i.e. towards customers).

The Green Product classification of the redesigned process is valid as long as the circumstances do not change (ceterus paribus). Once a year the circumstances (competitors, improvements, customers, governments and other stakeholders) need to be evaluated to see if any changes have occurred.

![Diagram of Redesigned Green Product Classification Process](image)

Figure 7-1 Redesigned Green Product classification process
The remaining of this subsection describes the software, database and procedures of the redesign consecutively. It concludes with an implementation plan.

7.3.1 Software

The redesign is an Excel based tool. This tool executes as well the GFA Environmental Benchmark as the Life Cycle approach. The first sheet of the tool displays the inputs and outputs (see Figure 7-2).

The required inputs are the details of the new product and of the reference product. The product details of the new product have to be filled in in the uppermost table. All product characteristics need to be filled in or a product needs to be selected from the database. The same applies for the reference product, whose details have to be filled in in the second box.

The third and fourth boxes present the result. After filling in the required input data, Excel automatically calculates these outputs. When the Life Cycle score is unknown (and thus the field
is left empty), Excel estimates this value using the power relation. The differences between the reference product and the new product are calculated and shown in both percentages and in a visual output. This visual representation is an adapted version of the Eco-compass (Fussler and James, 1996). The reference product is seen as the base case. The base case always scores a 0 in the four dimensions. The new product is then given a score relative to this base case on a scale of −2 to 2 in each dimension. The precise score depends upon the percentage increase or decrease in performance (see Table 7-2) (adapted from Fussler and James, 1996).

<table>
<thead>
<tr>
<th>Code</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change</td>
<td>≥10% degradation</td>
<td>&lt;10% degradation</td>
<td>Equal</td>
<td>&lt;10% improvement</td>
<td>≥10% improvement</td>
</tr>
</tbody>
</table>

Table 7-2 Adapted scoring Eco-compass

The second sheet of the tool includes all calculations. Maintenance can be done here, e.g. when the definition changes from a 10% improvement to a 15% improvement this can be adjusted easily in this second sheet by changing the formulas.

A presentation of the process and the redesign has been made as a method of validation. The presentation is presented to the future users and experts. However, to secure the validity of the tool and its outcomes, the power relation should be tested for one product of every newly developed technology. An EcoScan LCA should be executed and compared to the estimated value using the power relation. If the abnormality is less than 5%, the power relation can still be used. Otherwise, new research might be necessary.

### 7.3.2 Database

The tool is linked to a database (third sheet of the tool) with all 968 products from the representative sample. In the input section there is the option to select a (new and/or reference) product from this database. The inputs will then automatically be generated from the database and used for the calculations.

### 7.3.3 Procedures

There are three disciplines involved in the process. The responsibilities of each discipline are summarized in Table 7-3.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Development manager(s)</td>
<td>- Retrieve product characteristics &lt;br&gt; - Put product characteristics in Prisma</td>
<td>After the validation of a VPH</td>
<td>Results in Prisma catalogue</td>
<td>To enable product managers to use the characteristics</td>
<td>Same as currently</td>
</tr>
<tr>
<td>Product manager(s)</td>
<td>- Decide on reference product &lt;br&gt; - Put product characteristics in tool</td>
<td>After the legal and sustainability requirements checks</td>
<td>Results in the tool</td>
<td>To execute the GFA Environmental Benchmark and Life Cycle approach processes</td>
<td>Follow instructor paragrap</td>
</tr>
<tr>
<td>Sustainability manager(s)</td>
<td>- Check benchmark &lt;br&gt; - Add new product(s) to the database &lt;br&gt; - Internal communication</td>
<td>After candidate Green Products are known (before the third party review)</td>
<td>Check in the tool, adding in the database, and internal communication on the Intranet</td>
<td>To check the input and output, to update the database, and to enhance internal transparency on Green Product classification</td>
<td>Same as currently</td>
</tr>
</tbody>
</table>

Table 7-3 Procedures redesigned tool
To support the procedures performance measure record sheets have been developed for the performance parameters (see appendix XIV). These elaborate more on the responsibilities and procedures.

### 7.3.4 Implementation

Implementation of the redesign is relatively easy. The redesigned tool can replace the former GFA Environmental Benchmark file. The only difference is that the redesigned tool also includes the Life Cycle approach.

The future owner of the tool has been closely involved in this project. The new tool should be put on the Intranet so the product managers can download it. A meeting to explain the tool is not feasible since product managers are located throughout Europe. Therefore, an instruction (see Exhibit 7-1) should be put on the Intranet along with the tool.

---

**Instructions for the use of the Green Product classification tool**

**Input new product**

1. Check whether the new product (i.e. the product under consideration) is already in the database by scrolling down the options in the bottom input line. If not, go to step 2A, if yes, go to step 2B.

2. A: Enter the new product characteristics: name, customer (choose from options), lamp technology (choose from options), weight lamp (g), weight ballast (g), power system (W), luminous flux (Lm), lifetime 50% (h), mercury (mg), and if available the EI99 Life Cycle score (mPt).  
   B: Leave all boxes empty. Select the existing product from the database in the bottom input line.

**Input reference product**

3. Find an appropriate reference product. In order to do this find out what the youngest preceding technology for the same application is.

4. Check whether the reference product is already in the database by scrolling down the options in the bottom input line. If not, go to step 5A, if yes, go to step 5B.

5. A: Enter the reference product characteristics: name, customer (choose from options), lamp technology (choose from options), weight lamp (g), weight ballast (g), power system (W), luminous flux (Lm), lifetime 50% (h), mercury (mg), and if available the EI99 Life Cycle score (mPt).  
   B: Leave all boxes empty. Select the existing product from the database in the bottom input line.

**Output and visual output**

6. Save the Excel file under a new name and send it to the Sustainability Support Team for the check.

---

*Exhibit 7-1 Instructions redesigned tool*
7.4 Reflection

The redesigned process integrates two processes into one tool, which means a lot of time is saved. The process has become more efficient and is able to classify a large amount of products, which means the goal of the project is accomplished. However, it is useful to reflect on several aspects. This section reflects on the fulfilment of the design criteria, the solving of the problems from the problem definition, the fulfilment of the project assignment, the answering of the research questions, the delivery of the deliverables, and, finally, on the literature studied.

7.4.1 Reflection design criteria

A reflection on each design criterion is given in this subchapter.

- The tool can be used on the long term. However, the validity of the tool (i.e. of the power relation between energy efficacy and the comparable Life Cycle score) should be checked whenever a new technology is developed. This is necessary because it was not possible to check the tool using the representative sample.
- Comparisons are made with the most recent predecessor for the specific application (norm), which means the reference product scenario is a moving one. Since developments in the lighting industry take a couple of years, this implies that the reference product scenario is set for the middle long term.
- In the current database as well business as consumer products are included. Therefore, the tool can be used to classify products for both customer groups.
- The third party checks whether Philips does what it says it does and checks calculations based on samples. Since the database with the input data is linked to the tool, the required data is available and easily accessible for the third party.
- The PMS is described in paragraph 7.3. A database is linked to the tool (software) and the procedures are described as well.
- The performance indicators are made specific and measurable in appendix XIV. The indicators have to improve with 10%, which is an achievable goal (otherwise there would not be any or less Green Products). They are relevant since they are gained from the Green Product definition. The discriminant analysis (see paragraph 6.2.4) confirmed this statement. Lastly, the indicators are time-bound since they change for each product to be tested and they are always compared to the youngest preceding technology.
- Life cycle thinking is included in the tool since a Life Cycle score is included as well as separate measures for energy efficiency, weight and the amount of hazardous substances.
- Products that just come out of the innovation funnel (new products) can be classified using the redesign. They can easily be compared to the preceding technology for the specific application since that reference is present in the database.
- One of the outcomes of the redesign is a Green Product classification or not, so the tool is able to distinguish between correct (Green Product) and incorrect (no Green Product) performance. However, the tool uses the literal current Green product definition. Using this definition, energy saving lamps are classified as non Green products when compared to incandescent lamps since the amount of hazardous substances increases.
- Four performance measurement parameters are used to decide on the classification of the product (Life Cycle score, energy efficiency, hazardous substances and weight).
- The output of the tool is a Green Product classification or not.
- A functional benchmark is executed using the redesign.
- The average abnormality when compared to actual EcoScan values is 0% and the 95% reliability interval is −5% to 5% since an add-up percentage is applied to the power formula.
- The tool is simple since it is an Excel based tool with clearly defined inputs. Moreover, the tool makes sense since it integrates two processes into one.
- The tool is designed around the users (interviews), advanced (integrates two processes into one) and easy to experience (Excel based).

Most design criteria have been fulfilled. However, some remains open for discussion (i.e. the validity of the tool and the distinction between correct and incorrect performance).

7.4.2 Reflection problem solving
This section gives an evaluation towards the original problems of the project.

- The redesign offers a clear instruction and descriptions of the performance parameters. This solves the problem of unclear guidelines.
- The reference product to be used for the tool has been clearly defined (the most new preceding technology for the specific application).
- A database containing all data needed for the Green Product classification process has been linked to the redesigned tool. However, not all products are present in this database (only a representative sample).

The original problems have been solved with the new tool. However, the database solution is to be discussed.

7.4.3 Reflection project assignment
A reflection towards the project assignment is given in this section.

- An evaluation of the current process is executed.
- Requirements for the redesign of the Green Product classification process have been set.
- Options to adapt or replace the current process have been explored.
- Options for the redesign have been suggested.
- One option for the redesign is worked out.
- The tool is based on lamps measurements only. Therefore, it is not known whether it is applicable for the whole Lighting portfolio.
- External verification is possible.
- The process of Green Product classification has been redesigned.

The steps of the project assignment have been executed. However, the current tool is developed and tested only on product from the BG Lamps. The application of the tool for other BG’s is a subject of discussion.

7.4.4 Reflection research questions
This subchapter evaluates whether the research questions have been answered in this project.

1. The conditions for an efficient classification tool are described as the design requirements (see paragraph 7.1.3). The duration of the validity of a Green Product classification is discussed in paragraph 7.3.
2. Information on the data needed is described in Table 7-3.
3. The conditions for and the validity of the reference products are discussed in paragraph 7.1.2.
4. An analysis for key denominators is executed. The results (the use phase is the key denominator) are presented in paragraph 6.2.1.
5. The permitted tolerance in the outcome of the tool is set on 5% in paragraph 7.1.2.
6. Product clustering is analysed in paragraphs 6.2.6 and 6.3.1. However, further research is necessary to come to conclusions.
7. The data needed for a third party are all parameters, assumptions and calculations used. These are all easily accessible in the redesign.

Although all questions are answered, one answer is subject to discussion (i.e. product clustering).

7.4.5 Reflection deliverables
Four deliverables were specified for this project. This section reflects on the delivery of those.

- The research questions have been answered.
- Four validated scenarios for simplification of the current Green Product classification process are presented (see paragraph 6.3.4). However, these are only validated for the BG Lamps (i.e. not for the whole Lighting portfolio).
- Instructions for the tool and norms are described (see Exhibit 7-1).
- An implementation plan is given (see paragraph 7.3.4).

The deliverables have been accomplished. However, the validation of the scenarios is a shortcoming.

7.4.6 Reflection literature
A lot of literature has been studied in this project. Some articles were useful. However, most articles were too superficial to be of a real support. They only provided a general insight in the subjects benchmarking, Life Cycle approach and PMS. Therefore, most choices had to be based on practice. Subjects where literature was shortcoming (i.e. not adequate enough) were:

- Duration validity Green classification,
- Duration validity norms in Green benchmarking,
- Choice for reference products in Green benchmarking, and
- Product clustering in (Green) benchmarking.

7.5 Discussion
Most requirements have been fulfilled. The redesigned Green Product classification process is a simplification of the current process. Two processes are integrated into one and an estimation for the Life Cycle score is given, which means time is saved. The tool can be implemented for the BG Lamps. However, there are also some limitations (i.e. requirements that have not or only partly been fulfilled). These are discussed in this section.
• The power estimation method is only tested on 30 case studies since it was not possible to test on more cases. This is a weakness in the project as it lessens the validity of the tool. It is now necessary to check the validity of the estimation for one product of every newly developed technology. The same weakness holds for the validation of two of the other options (i.e. the options using an add-up percentage and multiple linear regression) and for the simplification of the process.

• The power relation is only tested on products from the BG Lamps, which means it can only be implemented for that BG. The power relation predicts the comparable Life Cycle score (mainly influence by the use phase) based on the efficiency in the use phase. Since it is expected that the use phase is the key denominator for products of the other BG’s as well (as this is true for electronic products in general), the power relation is expected to be valid for the other BG’s as well.

• Using the literal current Green product definition (i.e. as used in the redesigned tool) does not classify energy saving lamps as Green Products when compared to incandescent lamps since the amount of hazardous substances increases. However, there is a second order view of hazardous substances, which is not included in this research. The damage to the environment caused by mercury has namely two components: one caused by the mercury content in the lamp and one caused by electricity emissions (see Figure 7-3) (Ten Houten, 2008). The figure shows that mercury contents have decreased over the last years. It also shows that the total mercury emitted from electricity is higher for incandescent and halogen lamps compared to fluorescent lamp technologies. Moreover, the risk of mercury in a lamp is smaller since it is contained instead of dispersed through air emissions (ELC, 2005). These mechanisms are not always reflected on correctly in LCA’s (Ten Houten and Van Amelsfort, 2008). Looking at Figure 7-3, energy saving lamps could be classified as Green Products when compared to incandescent lamps since total mercury emissions are lower.

![Figure 7-3 Total mercury per Lumenhour over the Life Cycle](image)

• The database that is linked to the tool ‘only’ includes 968 lamps. Even though it is an instinctive sample of the Lamp portfolio, it is very well possible that a product manager would like to compare a new product with a product that is not included in the database.
• No clear conclusions could be drawn on the possibility of product clustering in the Green Product classification process. This implies more research is needed in order to come to a classification process that is based on cluster comparisons.

• An information gap is experienced in literature. Only a general insight in sustainability, benchmarking, Life Cycle approach, and performance measurement systems could be gained by reading literature. More research on sustainability and Green Product classification should be done and reported on in articles.
8 Conclusions and recommendations

This chapter reports on the conclusions drawn in the project and the recommendations given for the future.

8.1 Conclusions

Each phase of thesis project has lead to several conclusions. The most relevant conclusions are summarized in this subchapter.

In the problem analysis three problems have been identified:

- In the current Philips Lighting Green Focal Area Environmental Benchmark the guidelines regarding the input criteria (the quantitative composition of products) are not clear and strong enough.
- In the current Philips Lighting Green Focal Area Environmental Benchmark the guidelines for the choice of reference products are not clear and strong enough.
- A single database containing information on standard materials and amounts does not exist within Philips Lighting.

Several conclusions are drawn from the analysis of case studies. However, those conclusions only hold for the case study sample, which is why they are formulated as hypotheses:

- **H1**: The total Life Cycle score can be estimated using an add-up percentage to the use phase.
- **H2**: The total Life Cycle score can be estimated using multiple linear regression, i.e. Equation 6-1 through Equation 6-6.
- **H3**: Green Product classification can be estimated based on the discriminant function, i.e. Equation 6-7, using the parameters weight system/Lm*h, energy efficacy, mg mercury, and EI99/Lm*h.
- **H4**: The comparable life cycle score (EI99/Lm*h) can be estimated using the Power relation with energy efficacy, i.e. Equation 6-8.
- **H5**: Green Product classification can be done using technology-based clusters.

A representative sample is used to test the hypotheses when possible. However, Life Cycle scores are not known for other lamps than those in the case study sample. Therefore, an abnormality and sanity test have been executed. These tests have led to the conclusion that hypotheses 1, 2, 4 and 5 are considered options for the simplification of the Green Products classification process since they cannot be rejected.

The choice between the four options for redesign is made based on three criteria: fulfilling the design criteria, risks accompanied with the redesign option, and user preferences. Each option is scored on each criterion. Adding up all the scores leads to the conclusion that the power relation is the best option overall. Therefore, this option is used in the redesign.

The reflection on the redesign and the tool is generally positive:

- The redesign combines two processes into one process. One tool is designed for this process. Since the tool estimates a Life Cycle score, a lot of time is saved (i.e. the time
needed to perform a LCA). The process has become more efficient and is able to classify a large amount of products. The goals set are accomplished.

- Most design criteria are fulfilled, the problems found in the problem analysis are solved when implementing the redesign, the steps defined in the project assignment are executed, the research questions are answered, and the deliverables are gained.
- The redesigned tool could be used for more purposes than the one it is designed for. The input-output screen offers an easy way to see the results of improving a certain parameter immediately. Therefore, it could be of a great support in the EcoDesign procedures of the product development process.

Some limitations in the process and redesign are found.

- The validity of the option for the simplification of the process is a weakness since it was not possible to test on a representative sample. This also affects the duration of the validity of the tool since it might be possible that the estimating formula is not valid for new technologies.
- Testing is only done in the BG Lamps, which means implementation in all BG's is not possible (yet).
- The amount of hazardous substances has two factors while only one of them is included in the redesign.
- The database does not include all products, which limits the possibilities for reference products.
- No clear conclusions could be drawn on the possibility of product clustering in the Green Product classification process.
- The literature available was not satisfying since it lacked information on specific subjects.

8.2 Recommendations

Recommendations are given towards the Philips Lighting Sustainability Team and towards science.

- The redesigned process should be implemented in the BG Lamps as a pilot study. After testing the validity of the tool for the other BG's (i.e. comparing estimated and actual Life Cycle values), the redesign can be implemented for all Lighting BG's.

- The three hypotheses that have not been accepted based on tests with a representative sample should be investigated more intensively. Ideally, an abnormality test with a representative sample should be done. This would make the acceptance of the hypotheses much more valid.

- It is worth investigating options to include the mercury emissions of electricity in the LCA's so more valid results can be gained.

- Philips should link the tool to the online Prisma product catalogue. All inputs required are already available on Prisma for most products. These should be linked to the input screen of the redesigned tool. The output of the redesigned tool, the Green Product classification and the comparison behind it, should also be available in Prisma. Therefore, a connection between the output and Prisma should be established as well. This double connection secures that all products can be compared to each other. It enhances the internal
communication and transparency on Green Products. Moreover, it facilitates the usage of the redesigned tool.

- It would be very interesting to test the power relation at competitors. If the formulas are valid for them as well, easy external benchmarks become possible with the tool, since (comparable) Life Cycle scores of competitors can than be estimated as well.

- More research should be done on the four hypotheses that could not be rejected since more improvements on the Green Product classification process could be gained. More research about the hypothesized relations could lead to more attention in literature on this subject. This might trigger competitors to do similar research, which could again lead to more attention in literature.

- In literature research little information on the duration of the validity of a Green Product classification, the duration of the validity of norms in Green benchmarking, the choice for reference products in Green benchmarking, and product clustering in (Green) benchmarking could be found. More attention on these subjects would be interesting for science and a lot of companies.

- There should be done more analysis on the possibility of clustering products in subtechnology-based clusters (see appendix XV). It is likely that more significant differences can be found between subtechnology clusters since the standard deviations are probably smaller for these clusters.

- The communication on Green (branded) Products towards customers should be clearer. A file for explaining the Green Logo to customers is developed (see appendix XVI). Furthermore, a website should be developed containing the data used for the Green Product classification. It should be possible for customers to log in on a website with the product code and then find the Green Product details (output redesigned tool). Also an advertising campaign should help in providing more transparency on Green Products and the classification method.
Epilogue

This really is the end of my graduation project. It has been hard work, but if I look back now time has flown. When finalizing my thesis it is time to look back. During the project I often had doubts on where to go and what to do. I did not know anything about Life Cycle analyses. It was a difficult subject to get familiar with. If I read my thesis now, I think it worked out all right in the end. After all, the best way to learn is making mistakes during a project, discovering this and preventing it next time.

I am very happy I have been able to solve the problems found with my redesign. I have answered to the expectations, which makes me satisfied. However, I would have liked to test all hypotheses using a representative sample to make my results more valid.

On the personal field I think I really developed myself as a person during this project. I have learned so much. I learned how to handle a project of this size by myself, how to explain clearly what I mean and how to combine many people’s opinions in your work. I think I am now ready to start working!
List of abbreviations

BG  Business Group
BSC  Balanced Score Card
BEST  Business Excellence by focussing on Speed and Teamwork
BoM  Bill of Materials
CDM  Ceramic Discharge Metalhalide
CFL-I  Compact fluorescent integrated
CFL-NI  Compact fluorescent not integrated
CO₂  Carbon di-Oxigen
dc  Distribution Centre
e.g.  For example
eI  Eco-Indicator
Etc.  Et cetera
FCP  Function Creation Process
GE  General Electrics
GFA  Green Focal Area(s)
GLS  Incandescent lamp
HID  High Intensity Discharge
i.e.  Id est (that means)
incl.  Including
KPI  Key Performance Indicator
lca  Life Cycle approach
LCA  Life Cycle Assessment
LCI  Life Cycle Inventory
LCIA  Life Cycle Impact Assessment
LED  Light-emitting diode
MEDIC  Map & measure, Explore & evaluate, Define & describe, Implement & improve, Control & conform
MHN  Metal Halide N
NA  Not applicable
NPS  Net Promoter Score
PL  Bar CFL
PLE-C  PL lamp electronic, carre (4 legs)
PL-C  PL lamp, carre (4 legs)
PMS  Performance Measurement System
Prisma  Lighting product system
Pt  Point (1 Pt represents one thousandth of the yearly environmental load of one average European inhabitant)
R²  Measure for the amount of the variability that is accounted for using an estimating formula
REPA  Resource and Environmental Profile Analysis
RtBs  Reasons to Believe
SETAC  Society of Environmental Toxicology And Chemistry
SMART  Specific, Measurable, Achievable, Relevant and Time-bound
SON  High Pressure Sodium
SSL  Solid State Lighting (LED’s)
TL  Tube Luminescent
TLD (=T8)  Fluorescent lamp with a diameter of 26 mm
T5  Fluorescent lamp with a diameter of 16 mm
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>TQM</td>
<td>Total Quality Management</td>
</tr>
<tr>
<td>VPH</td>
<td>Value Proposition House</td>
</tr>
<tr>
<td>WECD</td>
<td>World Commission on Environment and Development</td>
</tr>
</tbody>
</table>
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