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Sustainability of Philips' depilation products

Diploma Thesis

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I would like to thank the following individuals for their sincere support during my diploma thesis. First of all I would like to express my thanks to Dr.ir. Frans J. M. Starmans, who was my supervisor at Philips for recruiting me into this thesis, for his patience to answer all my questions immediately and for guiding me through the whole work. I am also very grateful for the important roles, played by DI Dr. Nikolaus P.A. Mitterer and DI Georg Premm. Georg and Nikolaus were my supervisors at the university and guided me in a patient, challenging and motivating way. The other people who helped me a lot with my thesis; Ing. Johannes Glaboniat, DI Hubert Petz and Mag. Andrea Lakounig, I would also like to thank.

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Abstract

This diploma thesis was written for Philips Consumer Lifestyle in Klagenfurt, Carinthia. Philips started their first action plan on improving sustainability in 1994. As issues of sustainability gain more and more importance, companies are forced to apply methods and to switch to other materials to decrease their negative environmental impact. Overall goal of the thesis was the identification of possibilities to come up with an epilator execution that increases the sustainability of the product with lowest possible financial and minimal quality impact. To achieve this goal, this thesis covered several stakeholder aspects, which influence this product. In particular the stakeholders were Philips, the government and the NGOs.

First, the theoretical aspects on sustainability at company level were discussed to understand the view of the Philips Company itself afterwards. Several environmental assessment tools of products were described and considered in terms of effort. Furthermore a “Fast Impact Assessment” tool for materials was created because each of these assessment tools requires great effort. This tool supports the material selection process and the environmental impact of a specific material can be assessed very easily. In addition to that, the current view of the NGOs was briefly reviewed. Especially the Guide to Greener Electronics by Greenpeace forces companies to keep an eye on sustainability issues. A number of approaches for a green design were investigated as a general implementation for product designers. These approaches were formed to guidelines with the main focus on consumer goods. The main intention of these developed guidelines is to increase sustainability at acceptable costs of change.

Several ideas were generated with the help of these guidelines and one of them consisted in replacing the materials of the product with bio-based materials. To figure out the parts of the product with the highest improvement potential, the result of an environmental assessment tool (Life Cycle Assessment) was used. The investigation of biobased materials started with the collection of general information about biobased materials. The substitution potential of biobased materials was investigated to substitute fossilbased material. As a next step, the market of suppliers and materials was examined to determine potential biobased materials. The materials, which were found, were evaluated against the requirements of the material of the product. The best-ranked materials (including the material types PLA, CA, Bio- PA, PHB, and WPC) were ordered and processed to evaluate the behavior during the manufacturing process. Finally the investigation showed that some biobased materials already have the potential to substitute fossilbased materials. Furthermore it was concluded that the material price depends on the biobased content. The reason of using or not using biobased materials is not the costs of it because the costs per product will only be increased in a low percentage.

Zusammenfassung

Diese Diplomarbeit wurde für Philips Consumer Lifestyle in Klagenfurt, Kärnten verfasst. Das erste Programm zur Verbesserung der Nachhaltigkeit von Philips begann 1994. Das Thema Nachhaltigkeit gewinnt immer mehr an Bedeutung und zwingt Unternehmen Methoden anzuwenden und im speziellen andere Werkstoffe zu verwenden, die ihren negativen Einfluss auf die Umwelt verringern. Das Hauptziel dieser Arbeit war, die Ausarbeitung von Möglichkeiten einer Produktausführung eines Epiliergerätes, welche die Nachhaltigkeit steigert, mit möglichst geringen Auswirkungen auf Kosten und Qualität. Um dieses Ziel zu erreichen, wurden relevante Standpunkte mehrerer Interessensgruppen, wie Philips, die Regierung und NGOs betrachtet.

Zunächst wurden die theoretischen Gesichtspunkte von Nachhaltigkeit auf betrieblicher Ebene diskutiert, um die Ansicht von Philips danach zu verstehen. Mehrere Umweltbewertungswerkzeuge (unter anderem die Ökobilanz) von Produkten wurden untersucht und bezüglich ihres Aufwandes betrachtet. Da diese Bewertungswerkzeuge sehr aufwendig sind, wurde ein „Fast Impact Assessment" Werkzeug entwickelt. Dieses Werkzeug unterstützt den Werkstoffauswahlprozess, und bietet die Möglichkeit einer einfachen Beurteilung der Auswirkungen eines Werkstoffes auf die Umwelt. Ferner wurden die aktuellen Meinungen der NGOs überprüft. Vor allem die „Guide to Greener Electronics“ von Greenpeace zwingt Unternehmen dazu, ihre Nachhaltigkeit kontinuierlich zu überwachen und überprüfen. Eine Reihe von Green Design Ansätzen wurden untersucht, um eine allgemeine Grundlage für Produktkonstrukteure zu schaffen. Diese Ansätze wurden zu Richtlinien kombiniert, mit dem Schwerpunkt auf Konsumgüter. Der Hauptzweck dieser Richtlinien ist die Nachhaltigkeit, bei akzeptierbaren Änderungskosten zu erhöhen.

Einige Ideen wurden mit Hilfe dieser Richtlinien generiert und eine davon bestand darin, das verwendete Material durch ein biobasierendes zu ersetzen. Um die Bauteile mit dem größten Verbesserungspotenzial herauszufinden, wurden die Ergebnisse einer Ökobilanz verwendet. Die Untersuchung begann mit dem Erarbeiten von Grundkenntnissen über Biokunststoffe. Zur Erlangung von potentiellen Biokunststoffen wurde als nächster Schritt der Markt von Lieferanten und Produzenten untersucht. Darauffolgend wurden die gefundenen Kunststoffe mit den Materialanforderungen des Produkts bewertet. Die Biokunststoffe (einschließlich der Kunststofftypen PLA, CA, Bio-PA, PHB und WPC), welche die Anforderungen an besten erfüllen, wurden bestellt und verarbeitet, um das Prozessverhalten einzuschätzen. Das Resultat war, dass einige Biokunststoffe bereits das Potenzial haben, ölbasierende Kunststoffe zu ersetzen. Darüber hinaus wurde festgestellt, dass der Materialpreis vom Prozentsatz des biobasierenden Inhaltes abhängt. Der Hauptgrund für die Verwendung oder Nichtverwendung von Biokunststoffen sind nicht die Materialkosten, da diese sich auf die Gesamtkosten des Produktes nur in einem geringen Prozentsatz auswirken.

Table of content

1 Introduction

"Companies, that understand the consequences of climate change for their business not fast enough [...] are in danger of losing competitiveness, significantly faster than many can imagine today."[1]

This citation is a good introduction to this diploma thesis. In times of limited resources it is necessary for Philips to investigate the impact of its products on the environment as well as the future trends on the field of sustainability. The term "sustainability" itself has become increasingly important for Philips over the last years. As a result of this, Philips Consumer Lifestyle Klagenfurt decided to investigate its depilation products in terms of sustainability and this diploma thesis has been done it.

The following thesis will map out the current situation of sustainability and Philips' understanding of sustainability. The next chapter will be about assessment tools for analyzing the impact of the products of this company on the environment. Furthermore this thesis will cover the current view of the nongovernmental organizations, called NGOs. Moreover governmental regulations, which affect the products, will be described. This thesis will analyze several methods and tools in order to improve the sustainability of the products and will investigate the feasibility of biobased plastic.

[1] Graz/Volk (2003), p. 5

1.1 Royal Philips Electronics

Founded in 1891 by Gerard Philips, Koninklijke Philips Electronics N.V. (Royal Philips Electronics), most commonly known as Philips, is a worldwide operating and well-respected company with approximately 119.000 employees in more than 100 countries. Philips' headquarter is located in Amsterdam, Netherlands and they are a 25.42 billion (sales figure) business in 2010. In order to remain competitive, Philips invested 7% of their sales for research and development.[2] The following Table 1-1 shows several facts about Philips.

PHILIPS sense and simplicity	
Headquarter	Amsterdam, Netherlands
Founded	1891
Sales (in millions of euros)	25,419
Sales of Green Product (in % of total sales)	38%
Operational carbon footprint (in millions of tons CO2-equivalent)	1.8
Production Sites	118
Countries with sales and service outlets	100
Patent rights	50,000
Employees	119,001
Sectors	Healthcare, Consumer Lifestyle, Lighting

Table 1-1: Company facts[3]

Philips has a long tradition in the study of sustainability, thus Philips provides a sound knowledge on sustainability. They published their first environmental annual report in 1999. Since then, Philips has published one annual report every year that provides detailed information on the social, economic and environmental performance of Philips. Since 1994, Philips established the first action program to reduce their impact on the nature by setting up measurable targets.[4]

1.2 Philips Consumer Lifestyle Klagenfurt

Philips is divided into three sectors that are mostly equal in size. These groups are Consumer Lifestyle, Lighting and Healthcare. The products, sales figures and the number of employees are displayed in Table 1-2.

[2] Cf. Philips (2010a), p. 4
[3] Philips (2010a), pp. 4
[4] Cf. Philips (2010a), pp. 40

	Healthcare	Consumer Lifestyle	Lighting
Products	* Imaging Systems * Home Healthcare Solutions * Patient Care and Clinical Informatics * Customer Services	* Television * Personal Care * Audio & Video Multimedia * Domestic Appliances * Health & Wellness * Accessories	* Lamps * Consumer Luminaires * Professional Luminaires * Lighting * Electronics and Controls * Automotive Lighting * Packaged LEDs * LED solutions
Sales (in millions of euros)	8,601	8,906	7,552
Employees	35,479	17,706	53,888

Table 1-2: Sector facts[5]

The sector Consumer Lifestyle is split up into smaller business groups and one of them is skin and beauty (renamed to Personnel Care). The thesis was done for the beauty category, which is a subgroup of Personal Care. The above-mentioned structure of Philips is illustrated by the Figure 1-1. The figure shows the product categories, for which the Philips site CL Klagenfurt has the role of Innovation and Development Center or Production Center.

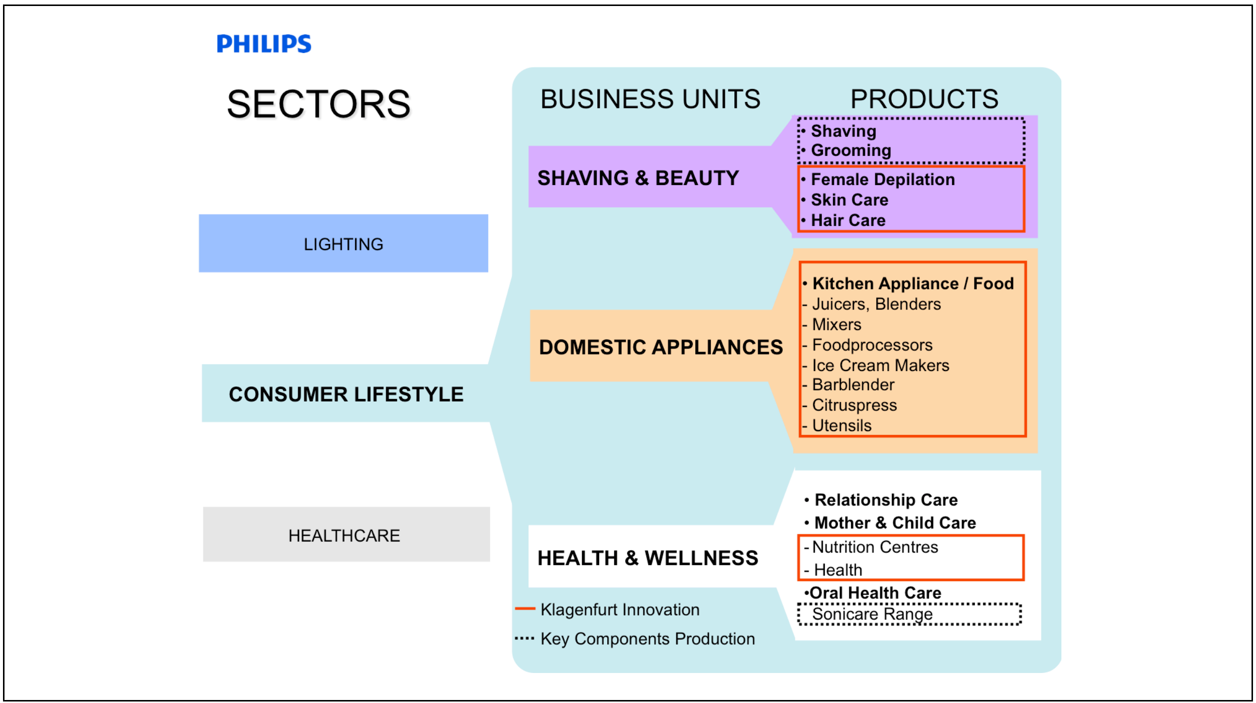

Figure 1-1: Structure of Philips in Klagenfurt[6]

[5] Philips (2010a), pp. 81
[6] Modified from: Philips (2010c)

1.3 Goal Statement of the Thesis

Overall goal of the thesis is the identification of possibilities to come up with an epilator or ladies' shaver execution and packaging execution that increases the sustainability of a product with lowest possible financial impact and minimal impact on quality.

As solution, one possible investigation direction is the replacement of existing materials by cradle-to-cradle replacement materials. Another direction of interest is the replacement of existing materials by materials that are completely biodegradable. Solutions for the product, that consists of electronics', plastic and metal parts, will partly differ from solutions for the packaging that consists of paper, carton, and plastics as separate parts or as laminates.

The thesis is roughly divided in four steps:

1. Understanding of the current sustainability situation at Philips and the current external situation as well. In addition to this the complete footprint of consumer electrics is considered. The footprint assessment is preceded by a short side step into available tools for making such footprint. To meet the cost and quality requirements, it will be needed to understand these. The last part of this step deals with an investigation of the topical view by nongovernmental organizations (NGOs) and a forecast of future bans and regulations.
2. After the investigation of the current situation the thesis lists possible solution directions for component groups and materials, and evaluation of footprint, cost, and quality aspects. For this still qualitative work the thesis takes one high- end epilator type as our working model. Packaging is taken along as well as the product itself and its accessories. Excluded are PCB-electronics, as these are a high-complex system with many components and materials that would require a separate study and approach for itself. Still taken along are the other electronics' parts like batteries, motor, cables, contact leads.
3. The third part covers the selection of a concrete solution for a product or packaging of choice, and the concrete evaluation of that solution. Here the study steps from qualitative into quantitative, but for the moment keep the theoretical nature. To manage the amount of work, three components are chosen to continue with.
4. In order verify the selected solution, it is necessary to proof the technical feasibility of the found solutions by realization and testing. This step is only possible with the premise of heavy support of suppliers, material selection department and the purchasing department.

The procedure of the above-mentioned steps is shown in Figure 1-2.

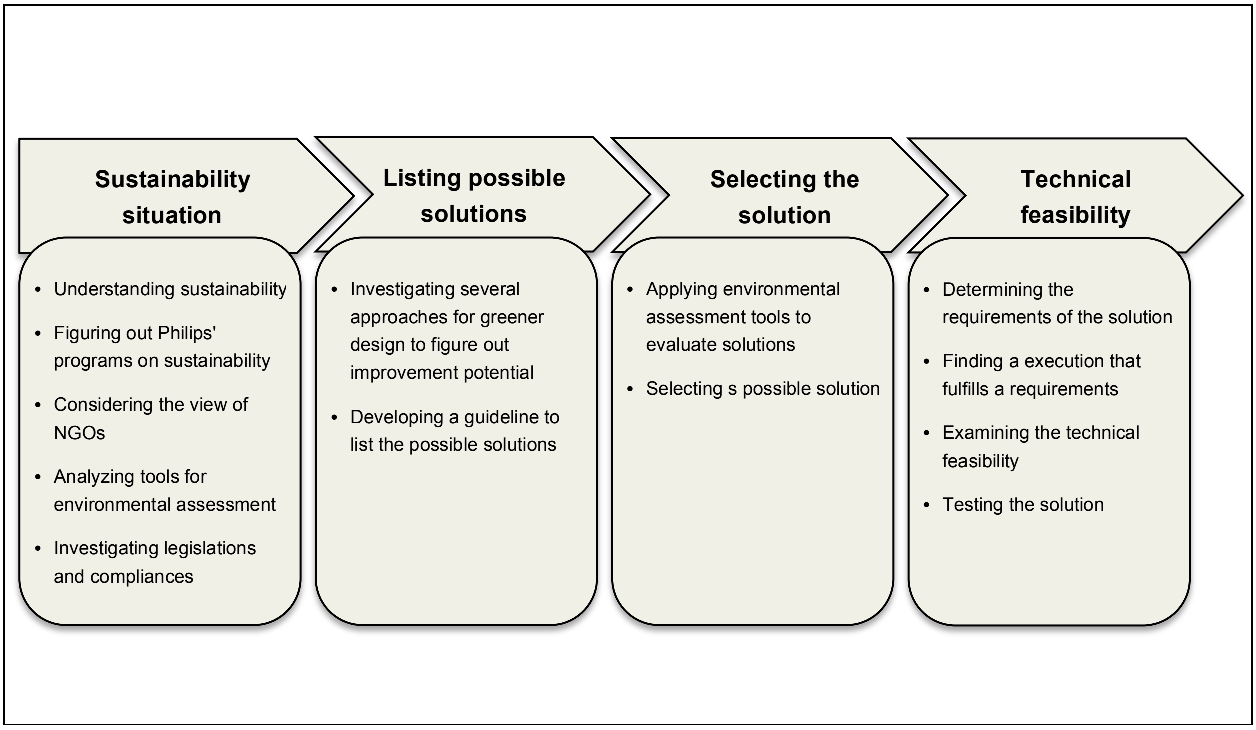

Figure 1-2: Procedure of the thesis

2 Theoretical Aspects on Sustainability at Company Level

In order to understand the current situation on sustainability it is very useful to start the consideration very holistic and then have a look at the entire company. There are a variety of meanings when it comes to the term "sustainability" and therefore the most relevant ones are chosen in the following paragraphs. Then the model of the sustainable development is described

2.1 Definitions of Sustainability and Sustainable Development

Due to the fact that there are so many different interpretations and explanations for sustainability out there, only a number were selected. The selection was made by the fact how good does the explanation fit to the topic of my thesis.

The origin of the word sustainability can be described by separating in the verb sustain, which is derived from the Latin "sustinere" and means "to uphold", and –ability.[7]

The Brundtland Report was one of the first reports that explained the term sustainable development and was published in 1987. This famous publication, particularly below citation, has influenced the whole mankind.[8]

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs." [9]

This citation was the first try to describe sustainable development and it started a new way of thinking for the economy and the society. In addition, it leads the reader to think of the correlations and to be aware of the holistic view.[10]

Another definition to consider was written by Konrad Ott[11]. He critically investigates the term sustainability and clearly separates it from sustainable development. In his publication he stated that the definition of sustainable development misleads the reader because of the murky notation of development. His definition is as follows:

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[7] Hulse (2007), p. 12
[8] Cf. Adams (2006), p. 1
[9] Brundtland (1987), p. 43
[10] Cf. Wallner/Schauer (2002), p. 153
[11] Cf. Ott/Thapa (2003), pp. 60

"Sustainability means that present and past persons have the same right to, on the average, equal opportunities for realizing their concepts of a good human life." [12]

In terms of this definition the author wants to combine the right- based morality ("same right") with a worldview objective ("good human life").[13]

These two definitions are both very holistic and reference more or less to the whole mankind but not on the sustainability of one specific company. As shown above the two citations particularly focus on two intersected pillars, the human and the ecological.[14]

Nowadays, the core of the common sustainability thinking at company level is based on the three-pillar model. These three pillars are the social, economic and ecological. The overall goal is to balance these three pillars and consider each of these within every business decision.

The shortest and also easiest definition is out of Macmillan dictionary, but it brings the issue of sustainability to the point only with one sentence.

"Using methods that do not harm the environment." [15]

However, this dictionary entry does not tell anything particular about social and ecological issues. As word environment could be interpreted as the ecological, social or the economic environment. This definition combines many different aspects with one simple sentence.

Meffert/Kirchgeorg[16] and Weizsäcker[17] developed a model to describe the main drivers of sustainable development. The description of sustainable development follows certain models:

- Circulation principle
  The circulation principle states, sustainable development is achieved by closing the material loop and by using the substances several times (recycling and reusing). The background is to change the linear material flow into a circular material flow.
- Principle of responsibility
  The intention of this principle is to reduce the gap of prosperity between industrialized and developing countries. In addition, the principle of responsibility includes accepting responsibility to maintain resources for further generations.

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[12] Ott/Thapa (2003), p. 60
[13] Cf. Ott/Thapa (2003), p. 60
[14] Cf. Gibson et al. (2005), p. 55
[15] Macmillan Education (2007), p. 1511
[16] Meffert/Kirchgeorg (2003), pp. 34
[17] Weizsäcker (1990), cited in Wohinz (2010), p. 6-5

- Cooperation principle
  The cooperation principle calls for the cooperation of all parties concerned (government, economy and science).

The 4 stages of ecologic development of a company, developed by Hipp/Rieger[18] are shown in Figure 2-1. This process can be used to analyze the strategic development of a company. The most important measurements are displayed in Table 2-1.

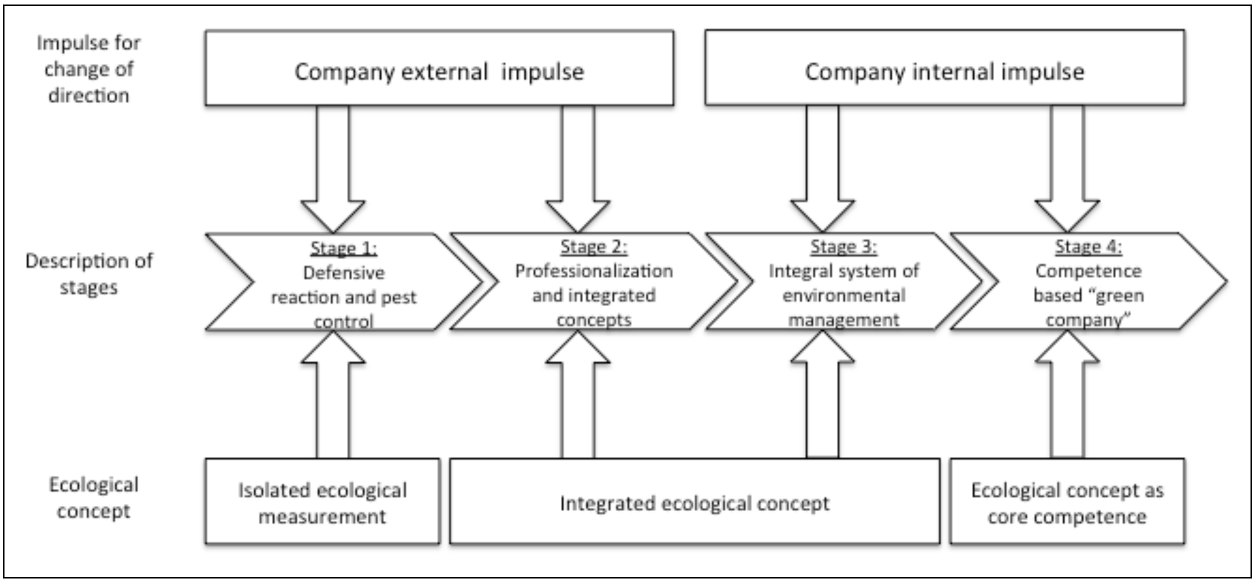

Figure 2-1: Four stages of ecological development of a company[19]

Stage		Description of the most important measurements
Stage 1	*	Additive, internal End-of pipe solution
	*	Dominance of disposal
	*	Focus on Production process
Stage 2	*	Integrated ecological concepts, that are constrained of internal measurement
	*	Environmentally sound product development
	*	Measurement are not yet implemented companywide
Stage 3	*	Optimized combination of external orientation and integrated ecological concepts
	*	Integration of normative, operative and strategic level
	*	Use the ecological orientation as advertisement
	*	Commitment to do more environmental protection as required from government
Stage 4	*	Use the ecological concepts as core competence, which offers competitive advantage
	*	Higher than average consumer benefit (product ownership versus benefit)
	*	Establishment of core competence in several levels: value chain, technology, processes

Table 2-1: Description of the most important measurements[20]

[18] Cf. Hipp/Rieger, in: ZfB 1/98, p. 41
[19] Hipp/Rieger, in: ZfB 1/98, p. 41

2.2 Three Pillars of Sustainability

The most common way of outlining the sustainability matters is to use the three-pillar version, which distinguishes between economic, ecological and social pillar

The economy circle immerses in society and the society immerses in the ecology as shown in Figure 2-2. This version of describing influence factors of sustainability is very suitable because it represents the normal research fields and scientific investigations. In terms of visualizing this model the pillars are sometimes interconnected and interdependent but in practice there just has been very rare interactions. The interaction has been very rare because it is not easy to think out of old administrative, academic and technical boxes.[21]

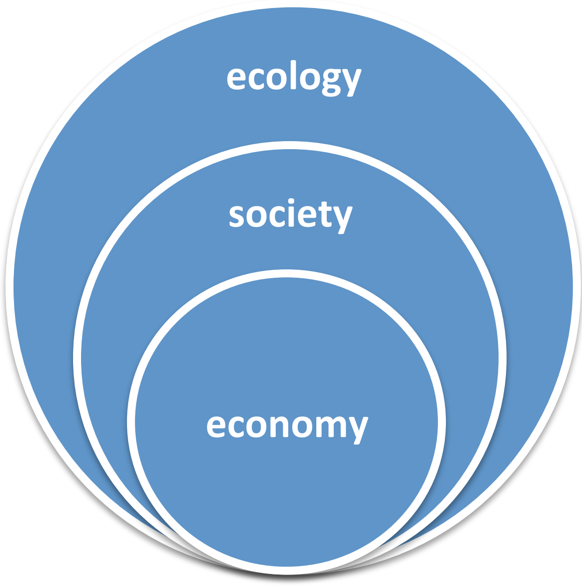

Figure 2-2: Circle of sustainability[22]

Table 2-2 shows detailed information of the pillars. There you can see the pillars in the first column. The middle column shows who are the proponents of this pillar and the last column describes the main emphases of the pillars.[23]

[20] Hipp/Rieger, in: ZfB 1/98, p. 41
[21] Cf. Gibson et al. (2005), p. 57
[22] Modified from: Gibson et al. (2005), p. 57
[23] Cf. Gibson et al. (2005), pp. 55

Pillars	Proponents	Emphases
Economic	Conventional and government interests: institution for trade liberalization	* Sustainable economic expansion to provide wealth to deal with environmental and social issues. * Efficiencies and substitutions to address ecological damage and resource depletion concerns. * Global market discipline and selected government interventions to encourage efficiencies and innovations.
Ecological/biophysical	Environmental NGOs, green ecology activists	* Growth as the enemy of sustainability . * Reduce demands on already overstressed biosphere. * Efficiencies not enough . * Must protect and rehabilitate natural systems, avoid invasive technologies, cut overconsumption by the rich, built basic economic security for the poor and stabilize of lower human pollution.
Social	Advocates of social justice and development reform	* Recognize the rich as well as the poor problems for sustainability. * Wealth/poverty not just economic: must enhance social and political as well as material equity. * Strengthen the assets, opportunities and the powers that allow people and communities to pursue sustainable options more successfully in their own ways and their own places.

Table 2-2: The three pillars of sustainability[24]

[24] Gibson et al. (2005), p. 55

2.3 EcoVision

The growth of awareness of sustainability programs has affected Philips as well. Since the 1990's a number of company programs under the name EcoVision have been set up. The first EcoVision was launched in 1998. Each EcoVison is only valid in a specific period and the goals should be achieved during this period. The main goals of the first program were to build one green flagship product per business unit and more important was the launch of the green focal areas that will be described in the following chapter. The succeeding EcoVisions are always more severe and include additional requirements for the company. The Table 2-3 shows the history of the published EcoVisions with their period and their main goal.

Title	Period	Main goal
EcoVision I	1998-2001	Making 'green' part of brand positioning, focus in green focal areas, green flagship products, increase of ecodesign, 15% packaging reduction
EcoVision II	2002-2005	Different goals for each department, to raise the bar
EcoVision III	2006-2009	Reduction of energy use, waste production, water use
EcoVision IV	2007-2012	Focus on further improving the environmental performance of products and day-to-day activities by 2012
EcoVision V	2010-2015	Focuses on pressing global issues and trends, to which it can offer meaningful solutions. These new targets broaden Philips' approach to sustainability well beyond the environment to clearly reflect the company's Health and Well-being strategy.

Table 2-3: The history of EcoVision[25]

In the following the thesis focuses on the two current EcoVisions, the EcoVision 4 and 5.

[25] Modified from: Groen (2011), p. 39

2.3.1 EcoVision 4

The EcoVision 4 has entered into force in 2007 and should last until 2012. The main goals of the EcoVision 4 are:[26]

- Generate 30% of total revenues from Green Products
- Double investment in Green Innovations to a cumulative EUR 1 billion
- Improve operational energy efficiency by 25% and reduce CO2 emissions by 25%, all compared with the base year 2007

Former CEO of Philips Gerald Kleisterlee announced in Philips' annual report that the revenue from Green Products was achieved 2009 and the investment for green innovation was achieved 2010.

2.3.2 EcoVision 5

In 2010, the current EcoVision 5 came into force. The EcoVision 5 is based on the WWF Living Planet Report 2006. In this report, the WWF presents the relationship between human development and ecological footprint very graphically and easily understandable. The human development index (HDI) indicates the well being of the countries and the footprint measures the demand on the biosphere. The life expectancy, literacy and education per capita GDP are the main drivers of the HDI. A country scores a high HDI value, if the value is above 0.8. Furthermore, the ecological footprint is calculated from the biocapacity available per person of the planet. If this value is lower than 1.8 global hectares per person, the country fulfills the requirement in order to be sustainable. Figure 2-3 shows the above-mentioned content. The goal of each country should be to meet the requirement of both, the HDI and the ecological footprint. If the country is in the blue rectangle then the country achieves the minimum criteria for a sustainable country.[27]

The chart (Figure 2-3) is the base for the 3 main goals of the EcoVision 5. The first goal is derived from the HDI in order to bring care and therefore achieving a better HDI score. The other two goals focus on the reduction of the ecological footprint.[28]

[26] Cf. Philips EcoVision 4, Accessed: 07.10.2011
[27] Cf. WWF (2006), p. 19
[28] Cf. Philips (2010a), p. 44

The derived goals are as follows:

- Bringing care to more than 500 million people
- Improving energy efficiency of Philips products
- Closing the material loop

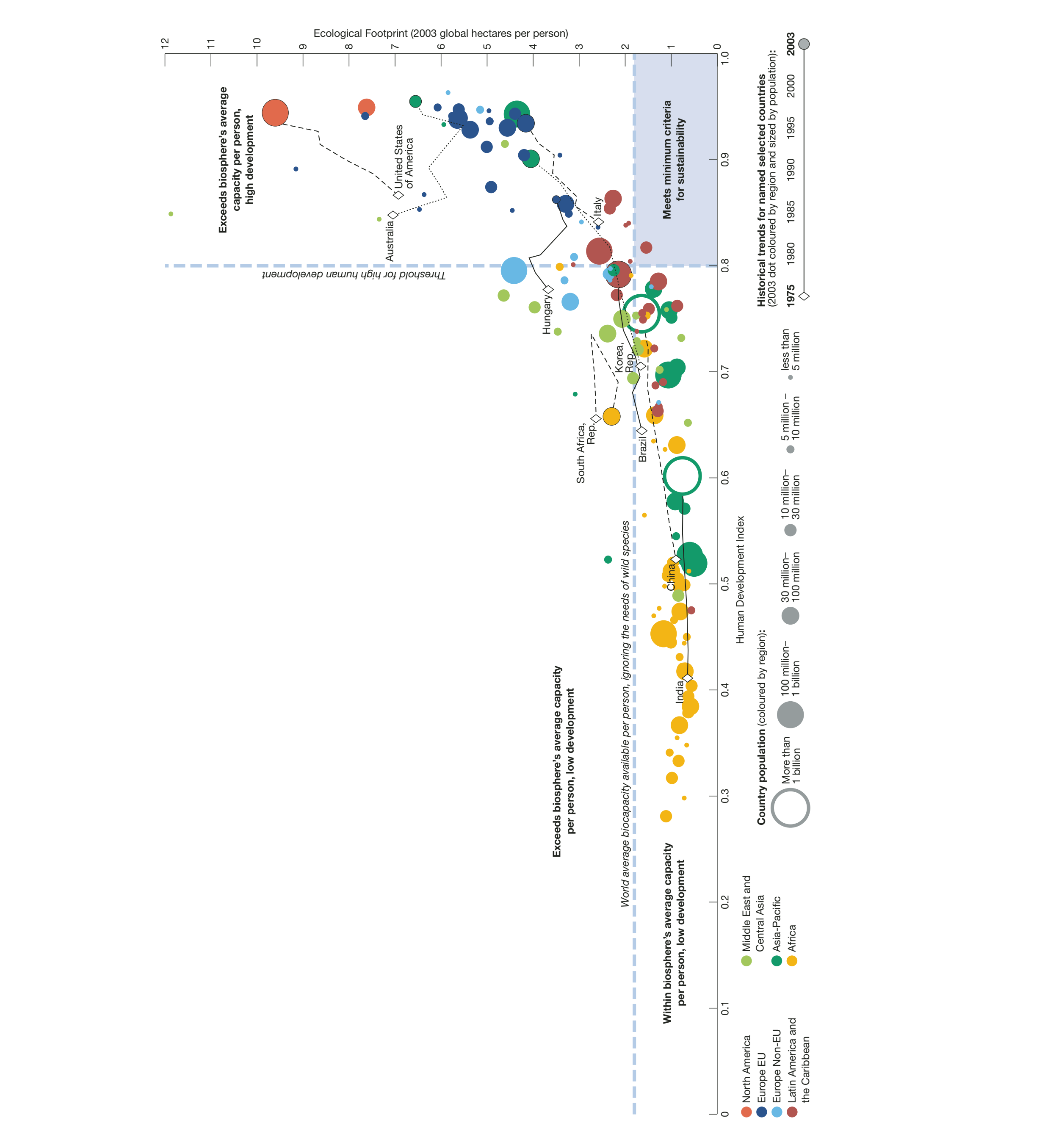

Figure 2-3: Human developing Index and ecological footprint, 2008[29]

[29] WWF (2006), p. 19

2.4 Conclusion

The easiest way to understand sustainability is the three-pillar model because it clearly illustrates the issues of sustainability.

The investigation of the term sustainability at company level showed that it is hard to find a simple description of sustainability. Philips has been a frontrunner in terms of sustainability. The goals of the EcoVision are very high and force the company to keep the environment in mind. Derived from the EcoVision every product category has different goals to be achieved every year.

Moreover, the annual report contains a whole section that deals with sustainability. On chapter is dedicated to present their achieved sustainability values and their measures for the future.

For companies these visions are very useful to drive for a better performance in terms of sustainability and the future development. In addition these vision helps to engage the employee.

3 Environmental Assessment Tools at Product Level

The next level from the top-down structure is the product level. This chapter deals with the assessment of products.

To estimate the impact of a product on the environment, I will mention two different groups of assessment tools. It is possible to classify the tools according to the significant environmental issue and the stakeholder requirements it takes into account. This separation is absolutely necessary due to the different characteristics. If the objective of the evaluation should be to assess the impact of different materials on the environment (for example CO2 consumption during all lifecycle stages), then it is useful to assess the material with one of the environmental issues' tools. The stakeholder requirements, on the other hand, include the other regulations like WEEE and RoHS.[30]

The tools, which are frequently used for the identification of environmental issues of a product, are:

- Life Cycle Assessment (LCA)
- Simplified LCA
- Material, Energy and Toxic emissions (MET
- Product Carbon Footprint

The description of these assessment tools is mainly quantitative figures (see chapter 3.1 - 3.4).[31]

For evaluating the stakeholder requirements are commonly used:

- Environmental Benchmarking
- Environmental Quality Function Deployment (EQFD)

These tools provide results that are mainly qualitative (see chapter 3.5-3.6). Below the Figure 3-1 visualizes the above-described tools and gives an overview on the subdivision.[32]

The chapter 3-7 deals with green product definitions at Philips. In order to evaluate the effort of the different mentioned tools, the last chapter 3-8 compares the different assessment tools.

[30] Cf. Kun-Mo Lee (2005), p. 15
[31] Cf. Kun-Mo Lee (2005), p. 15
[32] Cf. Kun-Mo Lee (2005), p. 15

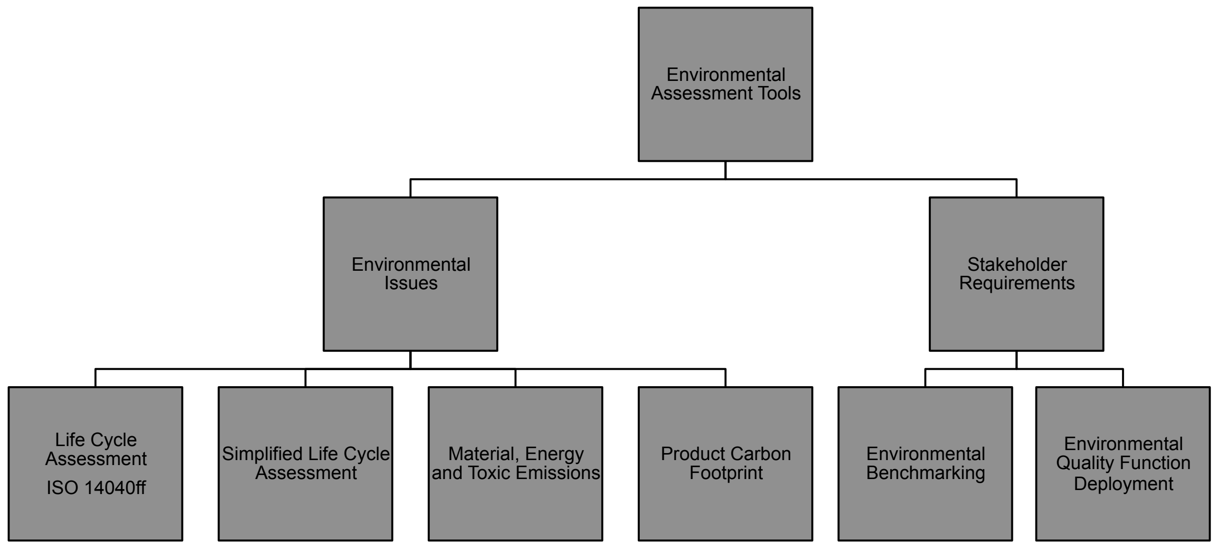

Figure 3-1: Overview of environmental assessment tools

3.1 The Life Cycle Assessment

Recently, many companies assess their product with this quantitative tool. This tool helps companies to figure out their products' impact on the environment. The life cycle assessment (LCA) shows the company how they could steer their impact and what are the main triggers of their products. In accordance with ISO 14044 the LCA can assist the company in:[33]

- Identifying opportunities to improve the environmental performance of products at various points in their life cycle,
- Informing decision-makers in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign),
- The selection of relevant indicators of environmental performance, including measurement techniques, and
- Marketing (e.g. implementing an ecolabeling scheme, making an environmental claim, or producing an environmental product declaration).

[33] ISO 14044:2006 (2006), p. V

3.1.1 General Information

In order to understand the LCA it is necessary to have a look at some definitions. Therefore, this thesis maps out the life cycle with its life stages.

One life cycle stage is one unit in the life cycle of products and represents the whole input and output of one life cycle stage. The example (Figure 3-2) shows which input and outputs can occur during one life cycle stage (unit process). The input could be raw material (for example: from a previous stage), energy input and additional material and the output could be any kind of emission, waste and the product itself.

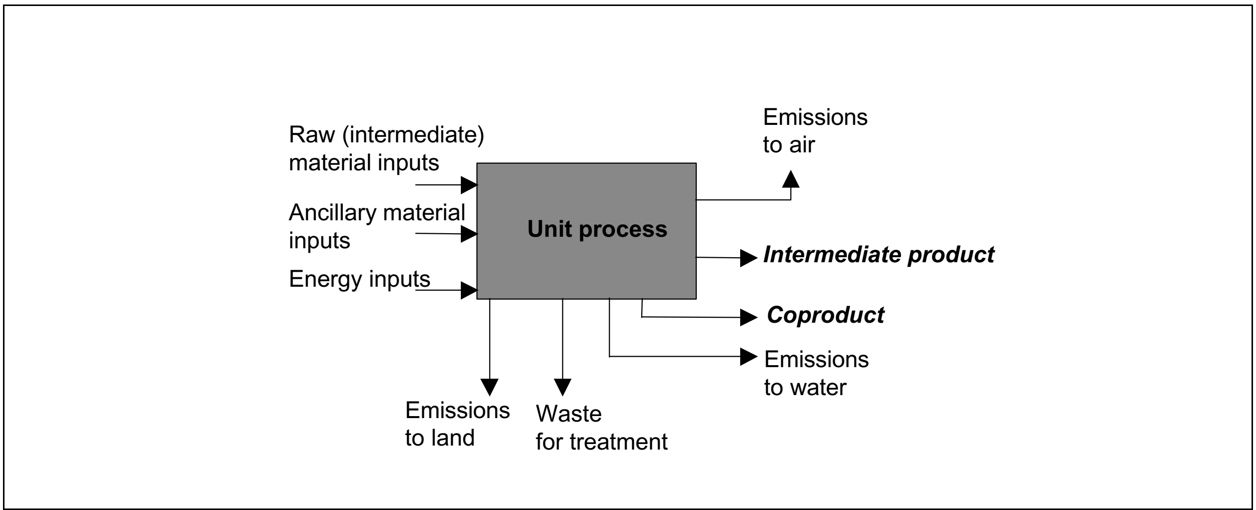

Figure 3-2: Conceptual example of a life cycle stage[34]

The entire life cycle is then a successive series of individual life stages. One example for a life cycle could be as follows in Figure 3-3.

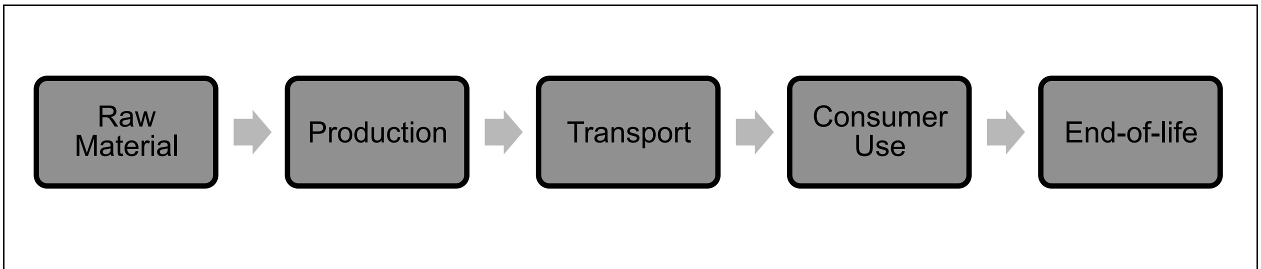

Figure 3-3: Example for a life cycle of products[35]

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[34] ISO 14049:2000(E) (2000), p.12
[35] Wimmer/Züst (2003), p. 9

To assess the entire impact on the environment of one product, the desired inputs and output of the entire life cycle must be cumulated. In the end there is a value that represents the impact. Due to the fact that the assessment is done with the different life stages it is very easy to figure out, which has to be improved. Some drivers of the different stages are listed in the Table 3-1 to give a flavor how to improve the products' impact. The Table 3-1 does not consist of all drivers.

Stage	Drivers
Raw material	* Material selection * Mining technology * Local suppliers
Production	* Used process technology * Dimensions and tolerances of the products * Energy efficiency
Transport	* Distribution of the sites * Used transportation system
Consumer use	* Power efficiency * Durability
End of life	* Design of Disassembly * Recyclability * Reusability

Table 3-1: Some drivers of the life cycle

3.1.2 Approach According to ISO 14040/ISO 14044

The ISO 14044 includes the structure and approach of an LCA. This guideline provides a structured framework for doing an LCA and divides an LCA into four main stages. The first one is the goal and scope definition, followed by an inventory analysis. The last stage is the impact assessment and besides there is part that is interlinked with all others, the implementation. The relationship of each stage is displayed in Figure 3-4: Stages of an LCA.[36]

[36] ISO 14040 (2006), p. 7

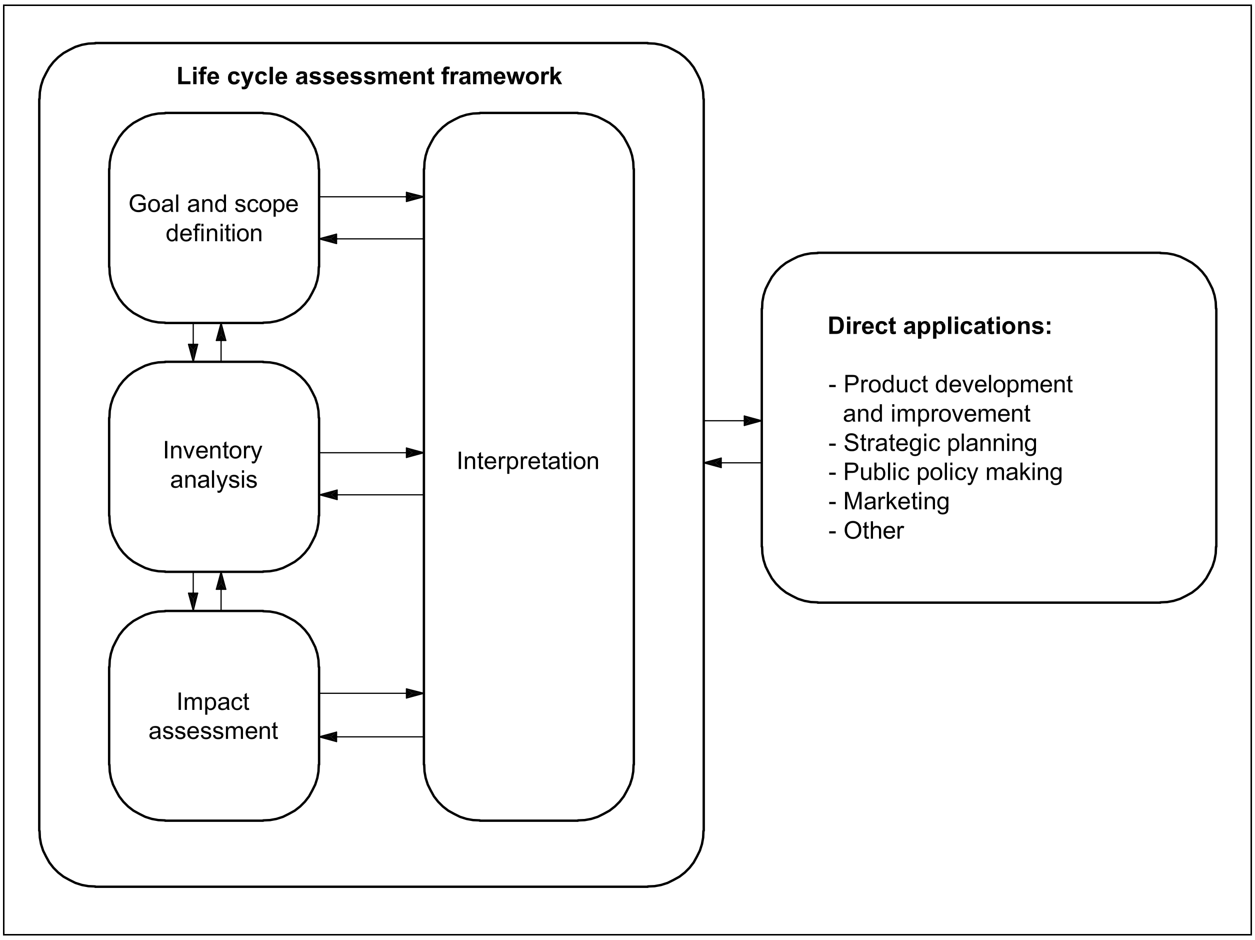

Figure 3-4: Stages of an LCA[37]

The goal definition addresses the following question: What is the reason for a LCA, who are the stakeholder, what is the product? The scope definition is used for defining the system boundaries, functional unit, and data parameters. When all functional units with their inputs and outputs have been determined and the system boundary has been set the next stage is started. The inventory analysis includes the data collection and the data calculation. This stage collects and processes all relevant data for getting a quantitative value of the life cycle. As a result of this stage there is a huge amount of collected data. In the last stage, the collected data is put into the context of current environmental impact. For example the CO2 value get transformed into global warming potential GWP. Throughout all stages of LCA extend the interpretation.[38]

[37] ISO 14040 (2006), p. 8
[38] Cf. ISO 14040 (2006), pp. 11

3.1.3 Methods

To estimate the impact on environment with an LCA, the two most common methods that are used these days are mentioned.

Eco-Indicator 99’

The Eco-Indicator 99’ is a method, which is based on weighting the desired parts to assess its impact. Another attribute is that the Eco-indicator 99’ uses a damage oriented approach. PRe Consultants developed this method and the data they used to create this method is related to Europe.[39]

All environmental impacts are related to the following three damage categories:

- Damage to human
- Damage to ecosystem quality
- Damage to resources

These damage categories were established with the help of 365 person of a Swiss LCA interest group. The group assessed the damage categories. The damage categories consist of 10 or more different impact categories, like ozone layer depletion, acidification, ecotoxicity, and resource extraction.[40]

The process of evaluating the indicator value is divided in three steps. Figure 3-5 indicates the process of the evaluation of an indicator value.

Step 1:

The left hand side of Figure 3-5 shows the lifecycle and the system, which are taken up in the inventory analysis according to the aspects in the green boxes.

Step 2:

The second step starts with the analysis of the resource, land-use, and the fate. The following sub-step is the exposure and effect analysis that leads to the damage analysis in the end of the second step.

Step 3:

After you have the results for the damage categories, the third step normalization and weighting finalize the process and in the end there is the indicator value that represents the impact on the environment.

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[39] Cf. PRe Consultants (2000), pp. 6
[40] Cf. PRe Consultants (2008), p. 22

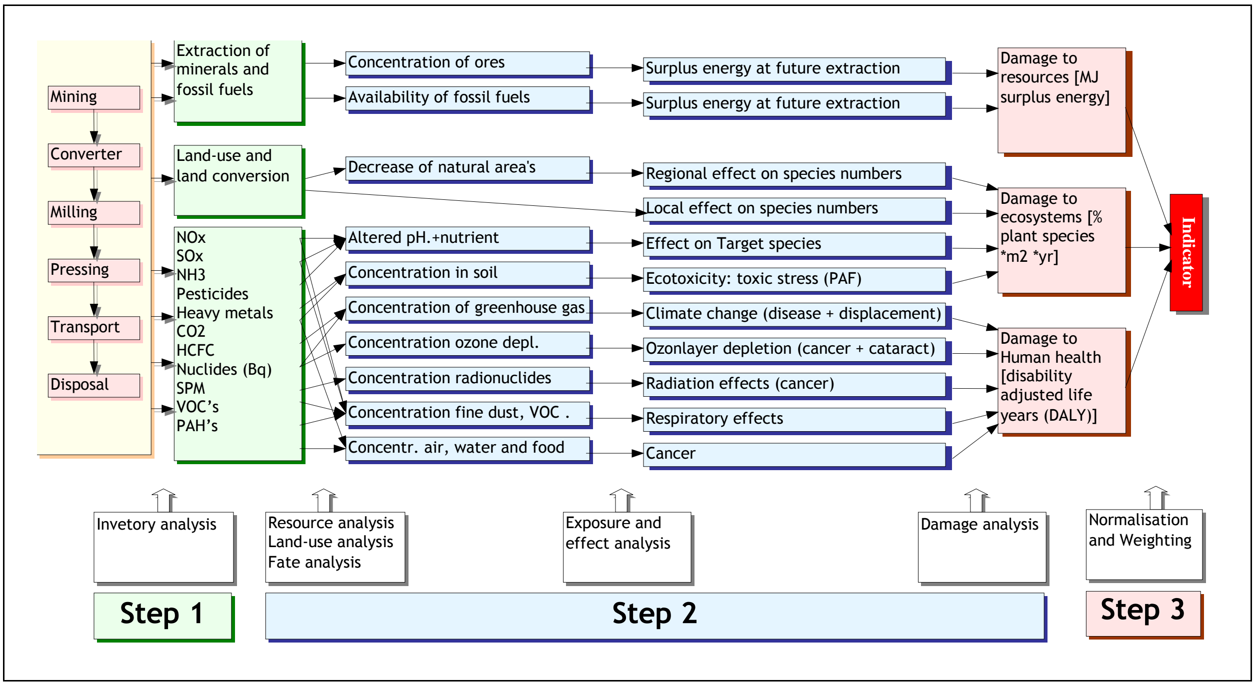

Figure 3-5: Detailed representation of the damage model[41]

When the indicator value is evaluated, the process of assessment is as follows. First, the product has to be disassembled and the material of each part must be determined. After this, each part is weighted and the weight of the parts is multiplied with the Eco-indicator value (depending on the material).[42]

The result has the unit milli-points (mPt) and represents the impact on environment. The scale is defined with 1 Pt is the value for one thousands of the yearly environmental load of one average European citizen.[43]

This method is very easy to use and to get a flavor of the environmental impact. Besides, there are many critical statements that this method is not accurate enough. The main advantage of this method is its simplicity and speed.

GaBi

The abbreviation GaBi stands for “Ganzheitliche Bilanzierung” in German that means life cycle engineering in English. This method was originally designed for describing a product during its lifecycle at the University of Stuttgart in 1990. This method contrasts with the EcoIndicator 99. As described earlier the Ecoindicator uses a bottom-up

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[41] PRe Consultants (2008), p. 22
[42] Cf. Philips (2010b), pp. 12
[43] PRe Consultants (2000), p. 9

method for assessing a product. On the contrary the GaBi operates with the top- down method.[44]

With the help of GaBi you can make an economic and as well as an ecological analysis. It is based on the following principle. Due to the different life stages of a product, each product causes material and energy transactions. These transactions are evaluated according to their harmfulness to the environment. By setting the system boundaries very clearly, it is easier to cope with the vast amount of data. The procedure begins with the specifications followed by the determination of system boundaries and the boundary conditions. The actual analysis is divided into three parts: economic, environmental, and technical. The result is an overall assessment of all three parts.[45]

3.2 Simplified Life Cycle Assessment

As a complete LCA is very expensive, it was demanded by the industry for another less time-consuming and expensive method. The “Simplified LCA” balances accuracy with cost and time consumption. The LCA becomes simplified during the first phase (Goal and Scope Definition). In this phase the system boundaries should lead to the simplest system. The result of the “Simplified LCA” only contains information that is relevant for the goal of the LCA study.[46]

Achieving a simplification can be done by two different approaches:

- Quantitative approach
  The first one is to reduce the effort of collecting the data. Some simplification could be: using the same data for different parts, do not assess all life cycles and so on
- Qualitative approach
  The qualitative approach is, for example, to use less accurate data for the assessment.[47]

Another assessment tool for simplifying the LCA is called “Streamlined LCA”. According to R. Horne[48], the “Simplified LCA” is pretty much the same as the “Streamlined LCA”. Both share the same goal to simplify the LCA in order to save costs and time.

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[44] Cf. Seebacher (2005), p. 88
[45] Cf. Eyerer (1996), pp. 7
[46] Cf. Christiansen (1997), cited in Kun-Mo Lee (2005), pp. 18
[47] Cf. Kun-Mo Lee (2005), p. 18
[48] Cf. Horne et al. (2009), pp. 26

3.3 Material, Energy and Toxic Emissions

The execution of a MET (Material, Energy and Toxic emissions) is less complicated than a LCA. As it is often not easy to collect all necessary data, the MET method simplifies the calculation. MET method divides the influence factors into three main groups. These are: material cycle (M), energy (E) and toxic emissions (T). An example of a MET assessment is shown in Table 3-2.[49]

Material cycles	Score	Energy use	Score	Toxic emissions	Score
Exhaustion of resources	0.8E-02	Greenhouse effect	1.1E-02	Ozone layer depletion	0
		Acidification	1.5E-02	Human toxicity	3.9E-02
		Smog	5.1E-02	Eco-toxicity	0.8E-02
		Eutrophication	2.2E-02		
M points	0.8E-02	E points	9.9E-02	T points	4.7E-02

Table 3-2: Example of a MET method assessment[50]

The Table 3-2 shows the different influence factors in the MET groups. Each value is normalized in order to be comparable to the others and to be able to sum each group. The Table 3-2 shows that for this product its energy consumption has the biggest improvement potential.

3.4 Product Carbon Footprint

The last quantitative method to measure the impact of a product on the environment discussed here is the Carbon Footprint. In their book on Ecodesign[51] Wimmer et al. describe how to determine the Carbon Footprint. The Carbon Footprint sums up the whole amount of GHG gas over the entire life cycle of a product. The GHG gases consist among others of CO2 and methane. The data for the calculation are limited to the GHG gases and come originally from an LCA. Having identified all GHG gases, they

[49] Cf. Kun-Mo Lee (2005), p. 17
[50] Kalisvaart/Remmerswaal (1994), cited in Kun-Mo Lee (2005), pp. 18
[51] Cf. Wimmer et al. (2011), p. 38

are converted into a unit, called GWP100, by use of a table from the IPCC. GWP100 stands for 100-year global warming relative to CO2.

Species	Chemical formula	GWP100
Carbon Dioxide	CO2	1
Methane	CH4	25
Nitrous oxide	N2O	298
Hydrofluorio carbons (HFCs)	-	124 - 14.800
Sulfur hexafluoride	SF6	22800
Perfluoro carbons (PFC)	-	7.390 - 12.200

Table 3-3: GWP100 of typical GHGs[52]

The method is executed in two steps. In the first step, all data are collected that are needed for the calculation. The life cycle is divided into five stages of life:

- Raw materials
- Production
- Distribution
- Use stage
- End-of-life

The calculation step converts the different input units into CO2-equivalent values by means of GWP100. These values are finally summed across all five life stages. The result is a CO2-equivalent value, which represents the environmental impact. By calculating the individual life stages it can be seen where the biggest levers for improvements are.[53]

3.5 Environmental Benchmarking

Benchmarking is the well-known and widespread tool for evaluating a product. The Xerox Cooperation describes the term benchmark by: "*The search for industry best practices which lead to superior performance.*"[54]

Environmental benchmarking (EBM) is based on the same principle; only the criteria to be compared are focused on environmental parameters. The procedure is described

[52] IPCC (2007), pp. 33
[53] Cf. Wimmer et al. (2011), p. 38
[54] Colding (1996), p. 7

with Philips as an example. The main focus areas are energy, toxic materials, recyclability, weight, and packaging. The procedure is shown in Figure 3-6. The environmental benchmarking process is divided in four main steps. The first step is to select the product of concern and then select three to four products of competitors. The competitors' products should be close to the product of interest. In the second step the specific parameters of the benchmarking have to be chosen in regard to the focus areas. The third step deals with the comparison of the product of interest with the competitors' products. The fourth step identifies in which area the product achieved a better score than the competitors' products. The result indicates which areas of the product should be improved.[55]

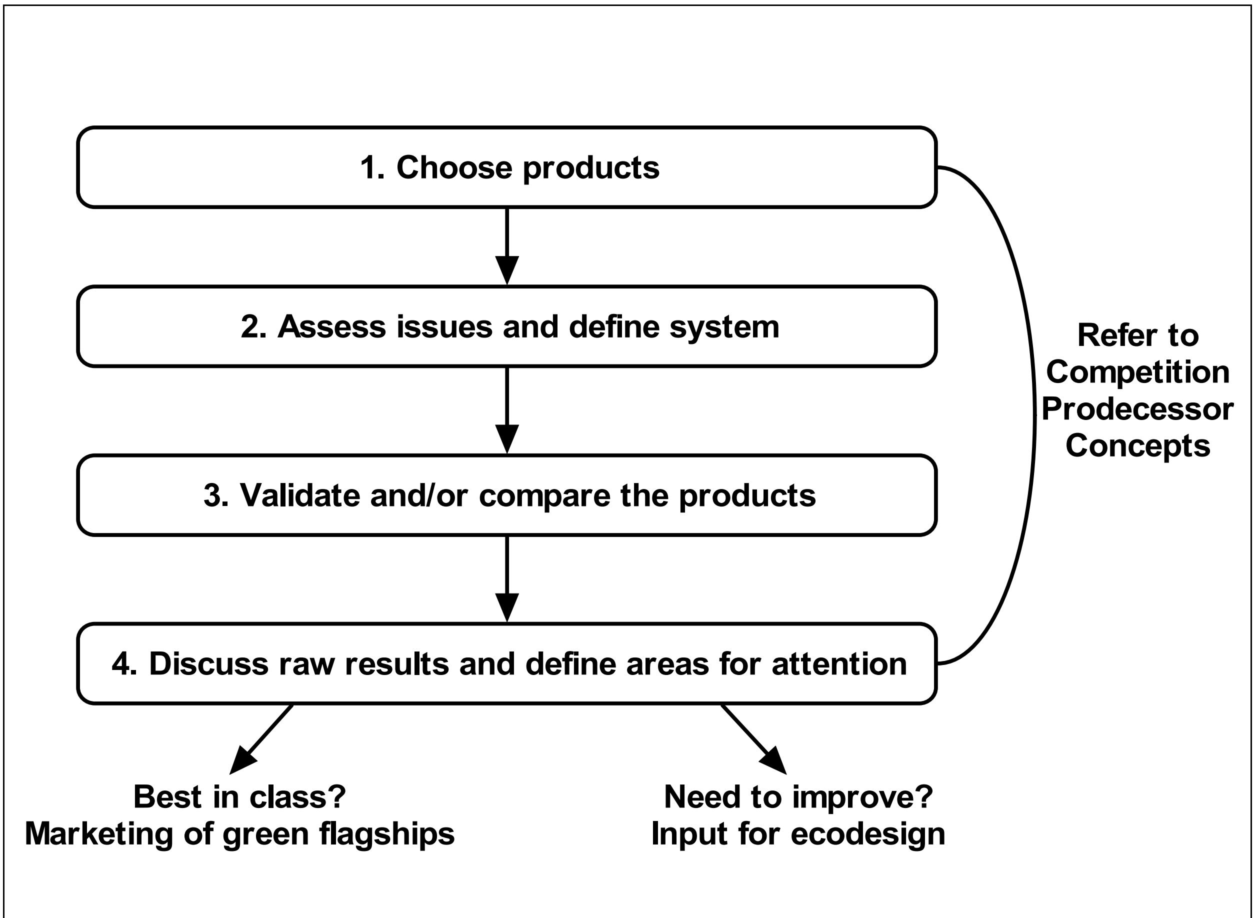

Figure 3-6: Environmental Benchmarking procedure at Philips[56]

[55] Cf. Kun-Mo Lee (2005), p. 19
[56] Deckers et al. (2000), cited in Kun-Mo Lee (2005), pp. 21

3.6 Environmental Quality Function Deployment

The normal QFD is a tool to link consumers' needs and the technical design parameters on the quality of the house. The goal is to identify the design parameters in terms of product quality. The EQFD method is based on the principle of the conventional QFD, however, the consumer needs are extended by environmental factors. These factors are weight, durability, etc. Figure 3-7 illustrates the House of quality according to Madu[57] combined with the modification by Wimmer et al.[58]

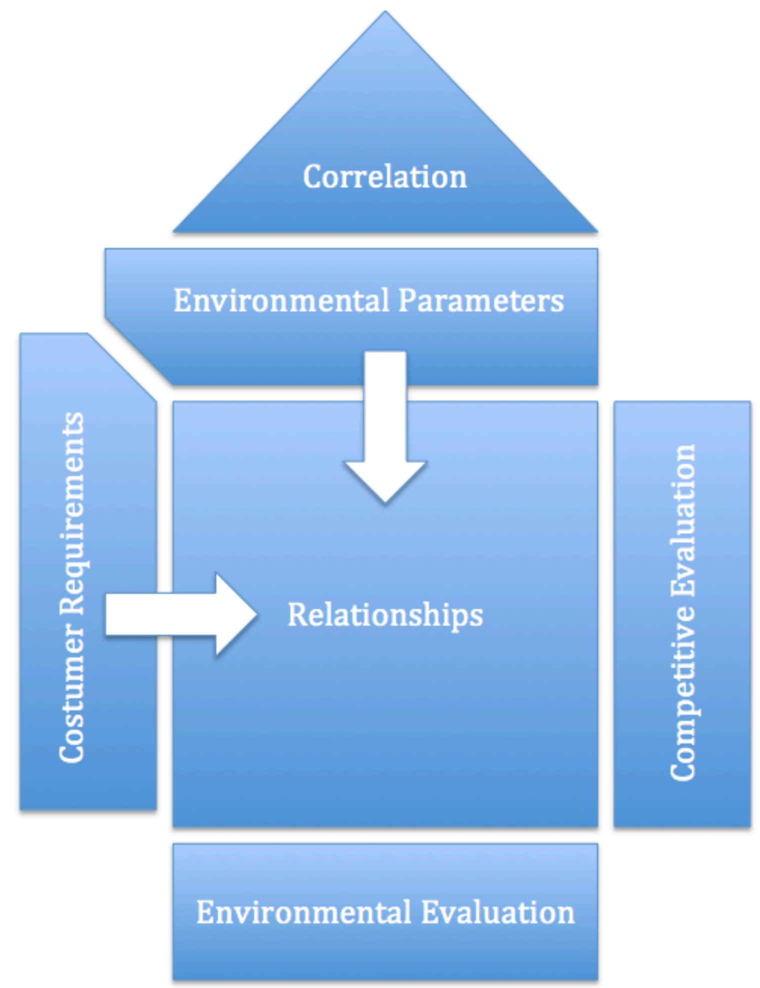

Figure 3-7: Environmental Quality Function Deployment

[57] Cf. Madu (2006), p. 25
[58] Cf. Wimmer et al. (2004), p. 73

On the left side are the consumers' needs to be combined with ecological parameters in the relationship field. In the roof of the house of quality, the correlation of these parameters is entered. On the right and bottom side, the parameters are then evaluated.

3.7 Green Product Definitions at Philips

Philips currently has two valid Green Product Definitions. The oldest version makes use of an EBM. The new version, valid since June 2011, does not evaluate the product relatively to other products but compares it to absolute values.

3.7.1 Old Green Product Definition at Philips (Way of Working)

To define a green product, Philips uses the environmental benchmarking method. Philips Consumer Lifestyle benchmark is based on 5 fields called Green Focal Areas (GFA). In addition to GFA, Philips does a LCA in their benchmarking process. The GFA column in Table 3-4 displays which fields are benchmarked. The Life Cycle Assessment column in Table 3-4 shows which fields are required for the LCA.[59]

		What is measured?	GFA	Life Cycle Assessment
	Energy Efficiency	Energy consumption per year	*	
		Energy consumption during lifetime		*
	Weight	Product and accessory weight	*	*
	Packaging	Volume (# products in 40ft container)	*	
		Packaging material & weight		*
	Recycling & Disposal	Material recyclability	*	*
		Recycled plastic or renewable sources	*	*
	Hazardous Substances	Elimination of hazardous substances	*	
		Reduction of particulate matters	*	

Table 3-4: Green Focal Areas and what is measured in Green Product benchmark[60]

The GFA lifetime reliability is not considered by Consumer Lifestyle and only assessed by Lighting.

[59] Cf. Philips (2010b), p. 4
[60] Philips (2010b), p. 4

The procedure is as follows. Philips takes two commercial competing products (the two most relevant competitors) and the predecessor for the benchmarking process. If the new product scores 10 % higher than the competing products the new product gets the green product label (is called a simple switch). The Figure 3-8 shows each phase of a benchmarking process as described above.[61]

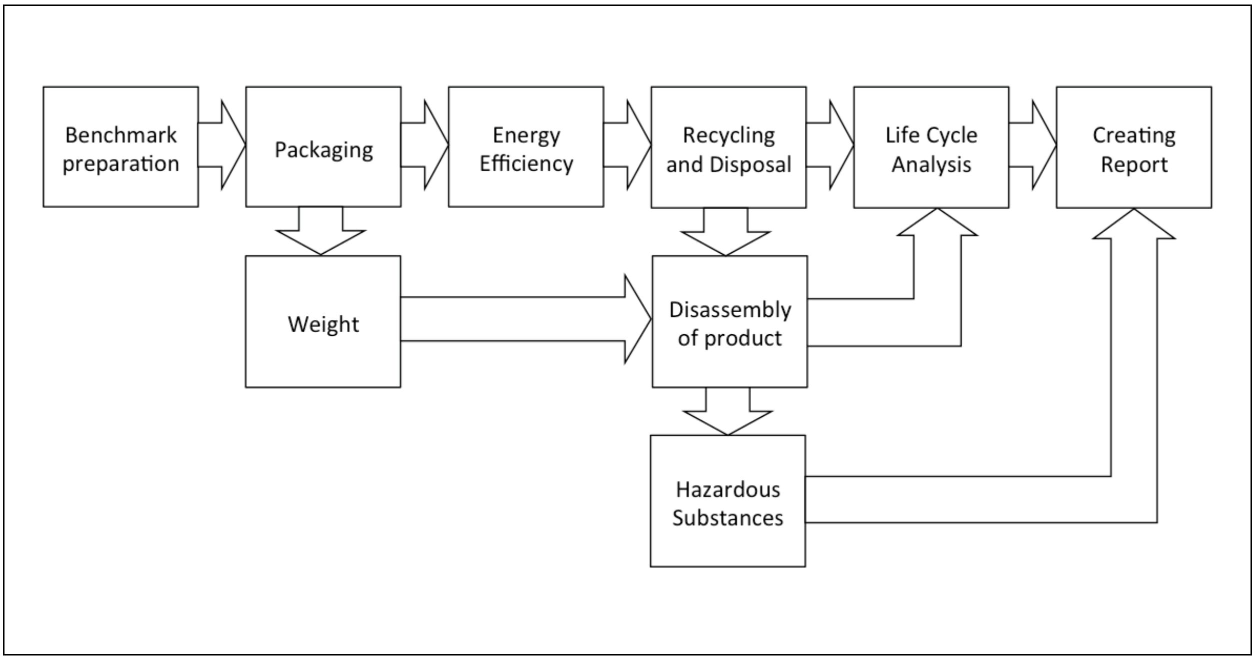

Figure 3-8: Flowchart of the complete environmental benchmark[62]

The flowchart shows the benchmark the process and covers all GFA and finalizes the assessment with a report.

3.7.2 New Green Product Definition

The new Green Product Definition is based on fixed values the product has to comply to. The Green Focal Areas are reduced to four main areas. These are: energy, packaging, substances of concern, and use of recycled materials. The product has to fulfill all requirements in order to get a green product label. The period of the requirements is separated in two phases. The first one is valid from 2012-2013 and the other one from 2014-2015. However the second phase is a forecast and has not been

[61] Cf. Philips (2010b), pp. 4
[62] Philips (2010b), p. 5

approved yet. The requirements of the second phase are stricter than the first phase. The Green Product Requirements for the first period are displayed in Table 3-4. [63]

Focal areas	Green Product norms 2012-2013 (a green product has to fulfill all requirements)
Standby adapter	• < 0.15 W no-load • Energy Star norm on battery charging
Standby/off-mode appliances	• < 0.25 W for non-attended products (connected to the grid permanently) without permanent info on display • < 0.5 W for non-attended products with permanent info on a display • < 0.5 W for attended products (disconnected from the grid after use) without permanent info on display
Energy consumption (if>10kWh/yr)	• Green level of external energy label *If not available then,* • Philips internal standard (*)
Packaging	• For the paper and cardboard used: > 90% recycled content or 100% from certified renewable sources. • For the plastics used: > 25 % recycled content or > 50 % bio-based content • No use of PVC and EPS • On volume ratio packaging/ product: • Vr<2 for products+accessories > 300 cm^3 ; • Vr<3 for products+accessories < 300 cm^3 ; • Vr<10 for products+accessories < 100 cm^3
Substances of concern	• All internal and external housing parts are PVC/BFR free • Adapters are 100% PVC/BFR free • Parts in direct food contact are BPA free
Use of recycled materials	• Building up the basis, therefore no specific target

Supporting policies: Adapter policy; Packaging policy; Restricted Substances List; PVC/BFR free policy

Table 3-5: Green Product Requirements 2012-2013[64]

3.8 Assessment Tools Comparison

Ha described a comparison, which is based on three criteria to compare the effort of different environmental assessment tools. Due to the use of these criteria, it is possible to make a statement about the methods. The results of the study are shown in Table 3-6. The criteria are: [65]

- Cost and time
  For an effective use during the development process, short evaluation time is essential. Also important are the costs. Very little indicates high costs and much time-consuming

[63] Cf. Veen (2011), slide 1 et seq.
[64] Veen (2011), slide 3
[65] Cf. Ha (2001), cited in Kun-Mo Lee (2005), pp. 23

- Design applicability
  How understandable the data of the analysis is, in order to draw conclusions about an improvement in environmental performance. Very good indicates a good ability to draw serious conclusions
- Objectivity and accuracy
  This criterion describes whether the analysis is based on objective and accurate information. Very good indicates very accurate and high objectivity.

Criteria / Tools	Cost and time	Design applicability	Objectivity and accuracy
LCA	--	+/-	++
The MET points method	--	+	++
Simplified LCA	+/-	+/-	+
Environmental Benchmarking	+	++	+/-
EQFD	--	++	+
Carbon Footprint*	--	+	++
Old Green Product Definition*	+	++	+/-
New Green Product Definition*	++	--	-

++ : very good + : good +/- : moderate - : little -- : very little

* authors estimation

Table 3-6: Evaluation of environmental assessment tools[66]

The Carbon Footprint is very similar to MET method and therefore the same evaluation can be used. The Old Green Product Definition is an environmental benchmarking and the evaluation of the criteria for the New Green Product Definition was estimated.

In addition to the first evaluation, the Chemistry Innovation Ltd describes the effort in three dimensions as shown in Figure 3-9. On the vertical axis is an indication of the cost situation and on the horizontal axis as the result looks like (whether it is qualitative or quantitative). Also is shown in this diagram, at which time of the project the different methods will be applied. The Chemistry Innovation Ltd subdivides the methods into the grey shaded categories, which represent the above-mentioned methods. The diagram shows what methods can be done internally and which need external experts.

[66] Modified from: Ha (2001), cited in Lee (2005), p. 24

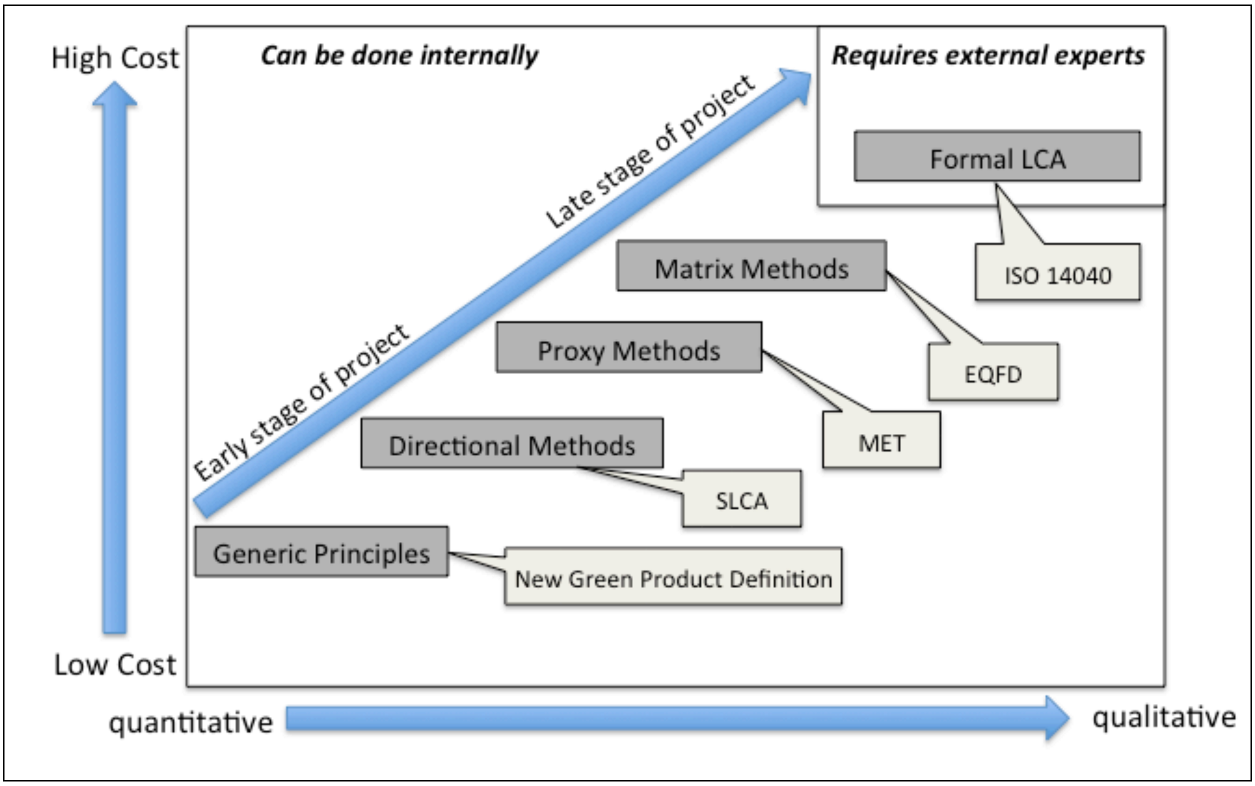

Figure 3-9: Comparison of various assessment tools[67]

For example: one assessment with the Eco-Indicator 99' method (LCA) costs 2.000 to 3.000 € at the University of Graz. According to a phone call with PE International (offering an LCA based on GaBi), one LCA with GaBi costs 10.000 to 20.000 € for each product. In addition, the training to do such an LCA also costs 10.000 to 20.000 € depending on the consumed training packages.

3.9 Conclusion

The above-described methods are commonly used by the industry nowadays. In order to use the most suitable method it is necessary to know the goal of the assessment. For example, do you want to get a quick result or do you want to have a very detailed assessment?

The current top companies that offer LCA software are PRe consultants (SimaPro) and PE International (GaBi). Besides, there is open-source software that is called earthster, which is very applicable.[68]

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[67] Modified from: Chemistry Innovation Ltd (2011), p. 38
[68] Cf. Earthster, Accessed: 26.10.2011

4 The View of the NGOs

In order to get an insight how sustainability is seen outside Philips and the scientific world, the view of some Non Governmental Organizations (NGOs) has been investigated. These organizations play a major role in shaping the public opinion, especially in the area on sustainability of products. NGOs often advice companies, to deal mindfully with the environment and they certainly are the voice of the environmentally conscious consumer. For example, until 2008 Philips did not take back their old products. As a result some members of Greenpeace decided to deposit the electronic waste in front of the Philips's headquarters all around the world.[69] With such actions the NGOs show that they can become active if companies do not protect the environment.

Since there are a large number of NGOs in the world, the thesis covers the most influential and largest NGOs. To get to the names of the NGOs, a list of NGOs by Esty/Winston[70] was used as base.

4.1 Greenpeace

Greenpeace is one of the biggest NGOs worldwide and has offices in 40 countries. One of their programs is concerned with the evaluation of companies in terms of toxic chemicals. They developed a rating system for all companies that is continuously updated. The results are assessed in view of three main goals that are to force companies to:[71]

- Clean up their products by eliminating hazardous substances.
- Take back and recycle their products responsibly once they become obsolete.
- Reduce the climate impacts of their operations and products.

The current edition of this ranking was published on October 26, 2010 and includes 18 top companies.

The calculation of the end score is made as follows. The data, which are needed for this ranking is gathered from the Internet site of the companies. The maximum score is 51 and is converted in the range 0-10. The best performance is represented with 10 points. The points are made up of the following criteria and are displayed in depth in the

[69] Cf. Greenpeace Press Release, Accessed: 11.10.2011
[70] Esty/Winston (2006), p. 69
[71] Greenpeace Guide to Greener Electronics, Accessed: 20.10.2011

Appendix III. The outcome of this calculation is the ranking, which is illustrated in Figure 4-1.

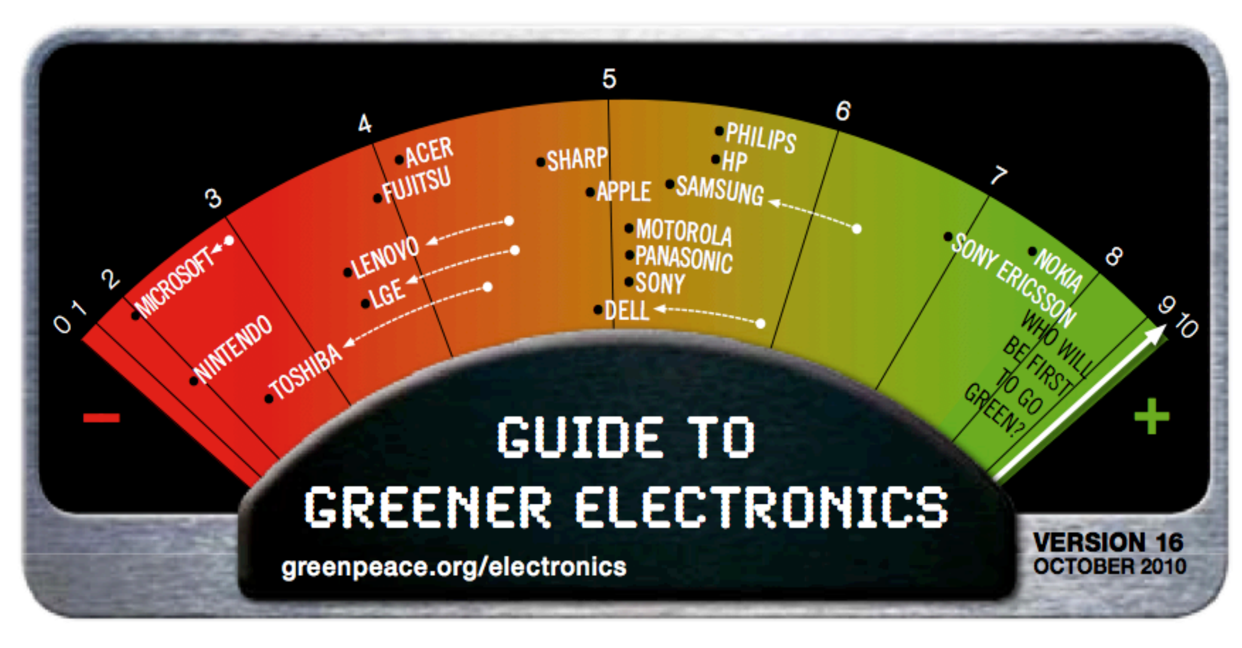

Figure 4-1: Guide to greener electronics Version 16, October 2010[72]

The Figure 4-1 shows that Philips takes the 3rd place in this ranking. Philips scored not higher than 5.5/10 points due to the following facts: The performance on voluntary take back actions was not implemented and the recycling activities were very bad. Although Philips is one of the top scores on energy, lower the GHG emissions, and lower the carbon footprint.[73]

In order to get in detailed information, a telephone interview with Austrian Greenpeace Office (Mrs. Claudia Sprinz, 23.05.2011) was made. Some notes of the interview were described in the following paragraph.

Their main focus is on ceasing the usage of materials like PVC, Phthalate etc. Besides they advice companies to develop products that are designed for a longer durability, however no one sticks to that. As one solution Mrs. Sprinz mentioned to make the battery change, because this will be the first part that will break down. Recycling opportunities should be easily for consumers. A system with modular components could significantly improve the sustainability. For example, if one part is broken the broken

[72] Greenpeace Guide to Greener Electronics, Accessed: 20.10.2011
[73] Cf. Greenpeace Guide to Greener Electronics, , Accessed: 20.10.2011

part could be rebuyed instead of buying a new product. If raw material is used, always take into account the working conditions at the mining sites because sometimes they are very bad and unhealthy for employees. The products should be designed in accordance with the principle of the founder of Bauhaus, which consists of three main pillars: Beauty, Functionality and Sustainability. Using a kind of deposit for products to ensure that the consumer brings back the discarded product. They advocate Cradle- to-cradle is as good approach to increase sustainability but always have in mind the people's health. Mrs. Sprinz stated: No packaging is the best packaging and a reusable packaging could help to manage the vast amount of waste.

4.2 Natural Resources Defense Council

Founded in 1970, the Natural Resources Defense Council (NRDC) have 1.3 million members nowadays, the headquarter is located in New York City, and they are mainly operating in the United States of America.[74] The NRDC runs many programs on environmental issues. The main objective of these programs is to reduce the carbon footprint.

One of the programs is called Smarter Living, which provides lots of advices for the consumer. The Smarter Living program is separated into five main parts:

- Food
- Health
- Home and yard
- Workplace and schools
- Smart shoppers guide

The health part provides a very helpful tool to let customer figuring out the background of some chemicals used in every day products. In addition, it also states the disease that is caused by these chemicals and in which product you can find it. These chemicals are among others (Appendix IV shows the full list):[75]

- Bisphenol A (BPA)
- Formaldehyde
- Lead
- Nanomaterials
- Phthalates

[74] Cf. NRDC, Accessed: 19.10.2011
[75] NRDC Chemicals, Accessed: 19.10.2011

Moreover, they run programs to evaluate several electronic devices, for example, TVs with the action program: The Top Ten USA's Most Energy Efficient Small TVs. The method behind this ranking is to measure all different energy modes of the TV in accordance with the Energy Star Version 5.0. [76]

4.3 Others

Environmental Defense Fund

The Environmental Defense Fund EDF is based in the United States of America and is focused on the North American continent. They mainly deal with issues related to global warming, ecosystem restoration, oceans, and human health.[77]

The human health issue includes the item "Safer Chemical", which aims on chemicals used in the household. They show at this point how dangerous the chemicals are. The dangerous chemicals in the home are as follows: [78]

- PFCs: Perfluorinated compound, used in cookware, clothing, food containers, carpets
- BPA: Biphenyl A, used in food can, baby bottles, receipt paper, CDs and DVDs
- Formaldehyde: used in carpeting, soaps, cabinetry, glues and adhesives
- Phthalate: used in paper, vinyl tile, wood finishes and lacquers
- Toluene: used in paints, flooring adhesives, adhesive remover
- PBDEs: Polybrominated dephenyl ethers, used in furniture, electrical equipment, TVs and computers

EDF also refers to diseases, which can be caused by these chemicals. Some of these diseases are: Fertility problems increased up to 40% between 1982 and 2002, and these are caused by PFCs, PBDEs and phthalates. Since 1980, the risk for asthma doubled, caused by toluene and formaldehyde. Parkinson's disease is associated with trichloroethylene and other chemicals. It is expected that the risk of disease will increase by 100% by 2030.[79]

[76] Cf. NRDC Top ten USA's most efficient small TVs, Accessed: 19.10.2011
[77] Cf. EDF, Accessed: 19.10.2011
[78] EDF Infographic chemicals your home and you, Accessed: 19.10.2011
[79] Cf. EDF Infographic chemicals your home and you, Accessed: 19.10.2011

World Wildlife Fund

The WWF is one of the largest NGOs in the world. Their focus is mainly on protecting nature, wildlife, seas, etc. They do not run campaigns with a focus on consumer goods, because it is not the topic of their core focus. This information comes from an email inquiry.

Sierra Club

Sierra Club was founded in United States of America, 1892. They have more than 10 programs with different focuses. One is especially important to mention here, the cleaner energy program with the guideline: Ten Things You Can Do to Help Curb Global Warming. This guideline advices to buy products that are Energy Star certificated and to look for products, which are easy to disassemble and therefore recyclable. In addition, you should avoid heavy energy consuming products.[80]

They heavily support the Guide to Greener Electronics established from Greenpeace. On their homepage they animate to consider the environmental performance of companies. Furthermore, the other programs deal with ceasing oil or gas, dumped water, green building etc.[81]

Conservation International

The Conservation International was founded 1987 and runs six initiatives. These are:

- Climate
- Fresh Water
- Food
- Biodiversity
- Health
- Cultures services

This NGO states to have a greener supply chain. Also they want better working conditions for mining of the raw material. The "Be A Greener Consumer" guideline advices the consumer to buy products that are made from recycled material or can be reused or recycled.[82]

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[80] Cf. Sierra Club Ten Things, Accessed: 20.10.2011
[81] Cf. Sierra Club Recycle More, Accessed: 20.10.2011
[82] Cf. Conventional International Greener Consumer, Accessed: 20.10.2011

In order to reduce the amount of waste, recycle all computer disks, CDs, videos, batteries, and use less hazardous, rechargeable Nickel-Metal Hydride batteries instead of common non-rechargeable batteries. Approximately 146.000 tons of consumer batteries are disposed each year. This only represents 0.1% of the total waste but the batteries are much more harmful due to their toxic ingredients.[83]

National Wildlife Federation

The National Wildlife Federation states that everyone should lower his carbon footprint and consider the amount of waste that gets in the trash bin. As a result, they advice the consumer to think of the following approach:[84]

- Reduce - Reduce the amount of garbage you create.
- Reuse - Choose to use things that have a long shelf life, or can serve another purpose after their first use.
- Recycle - If 1 and 2 aren't an option--recycle.

By establishing an own recycling program for electronic waste, they help the consumer to reduce their environmental impact. The waste can be sent to the NGO and they take care about the proper disposal or recycling. They accept, for example: Cell phones, laptop.[85]

Friends of the Earth

In comparison to the other NGOs the Friends of The Earth International describe themselves as an environmental network to uphold the earth. The members are located all around the world. In addition, Friends of the Earth also support a legislation framework for ecodesign. Regarding environmental product declaration, they would suggest the European Union to create one ecolabel, because currently there is a vast amount of ecolabels.[86]

According to their briefing note on Hazardous Waste Mountains, they heavily support the RoHS, WEEE, End of life vehicle, because these regulation helps to phase out the hazardous substances. However, this phase out could take 10 years, they critically mentioned.[87]

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[83] Cf. Conventional International Recycle Electronics, Accessed: 20.10.2011
[84] National Wildlife Federation Reduce Reuse Recycle, Accessed: 20.10.2011
[85] Cf. National Wildlife Federation Electronics, Accessed: 20.10.2011
[86] Cf. Friends of the earth (2007), pp. 2
[87] Cf. Friends of the earth (2004), p. 3

4.4 Conclusion

On the whole all NGOs focus on toxic chemicals. They describe on their homepages that before you purchase a product, you should always pay attention to the used materials. For example, there are homepages like www.marketcheck.at that evaluate a product based on aspects of the environment. In particular, Greenpeace has just developed a ranking system to evaluate companies according to their environmental performance. The criteria used are constantly being revised and the latest version will be presented in November 2011. These criteria include a new point, which was mentioned during the interview with Mrs. Sprinz, the lifetime of the products would be taken into account.

It is becoming increasingly important to work closely with NGOs. These organizations have in terms of sustainability a sound knowledge and are also ready to share this knowledge with companies. If companies do not operate in an environmentally friendly way, the NGOs also have opportunities to harm a company.

NGO	Founded	Members	Areas served	Relevant Programs
Greenpeace	1971	2,860,000	Worldwide	Guide to Greener Electronics
Natural Resources Defense Council	1970	1,200,000	USA	Smarter Living
Environmental Defense Fund	1972	700,000	USA	Safer Chemicals
World Wildlife Fund	1961	> 5,000,000	Worldwide	none
Sierra Club	1892	1,400,000	USA, Canada	Cleaner Energy Program
Conservation International	1987	no data	Worldwide	Be a greener consumer
National Wildlife Federation	1936	4,000,000	USA	Reduce Reuse Recycle
Friends of the Earth	1969	> 2,000,000	Worldwide	Hazardous Waste Mountain

Table 4-1: Facts of the before-mentioned NGOs

5 Legislations and Compliances

The legislations and compliances have been increasing over the past few years and they will become stricter in the near future. The aim of legislations is to force the companies to reflect on used materials and to avoid toxic as well as harmful materials in their products. This chapter discusses the legislations that have the most impact on Philips. This selection of legislations consists of the REACH (Registration, Evaluation, Authorization and Restriction of Chemicals), RoHS (Restriction of Hazardous Substances), and the Philips Internal List of Restricted Substances.

5.1 Definition of Calculating Base

Before discussing RoHS and REACH, this paragraph starts with clarifying the main differences of the calculating base. Articles are the base for REACH, and are defined by: *“Article: means an object which during production is given a special shape, surface or design which determines its function to a greater degree than does its chemical composition”*[88] This definition says that an article could be anything from a part, a subassembly, an accessory, or a finished product. That is reason why Philips has its own interpretation: "articles can in general terms, be seen as all "loose or separated” parts in a box".[89] The following Figure 5-1 describes very well what Philips means by an article (presented by the example of Philips Table Light).

1 Product = 10 Articles (highlighted in red)

1. 1x lamp
2. 1x remote control
3. 1x foot (stand) of the lamp
4. 1x power adapter
5. 1x battery pack containing 3 batteries
6. 1x cardboard packaging
7. 1x plastic packaging of adapter
8. 1x plastic wrap batteries
9. 1x EPS cushions – not visible
10. 1x all manuals / books

Figure 5-1: Illustration of article definition[90]

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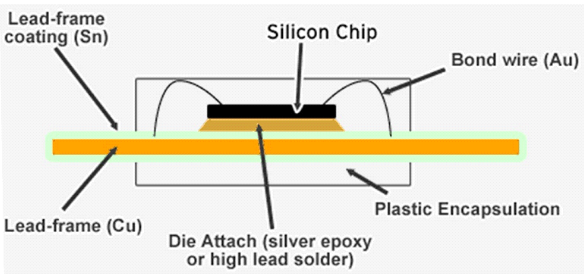
[88] REGULATION (EC) No 1907/2006 (2006), p. 54
[89] Philips (2011a), p. 13
[90] Philips (2011a), p. 13

On the contrary, the RoHS base their calculation on homogeneous material. This means that every substance is separately taken into account. For example, a PVC wire consists of two homogenous materials: copper and thermoplastic. The RoHS thresholds are then applied to each homogeneous material.[91]

To illustrate these different approaches, the next Figure 5-2 shows the difference between those, explained by a capacitor.

RoHS **REACH**



Substance 'X' < 0.1% at Homogeneous Material level means:
- Plastic encapsulation → X < 0.1%
- Bond wire → X < 0.1%
- Silicon chip → X < 0.1%
- Lead Frame coating (Cu) → X < 0.1%
- Lead Frame coating (Sn) → X < 0.1%
- Die Attach → X < 0.1%
- Etc.

Substance 'X' < 0.1% at Article level means:

X [Plastic encapsulation + Bond wire + Silicon chip+ Lead Frame coating (Cu) + Lead Frame coating (Sn) + Die Attach + ...] **< 0.1%**

Note that some parts within the article may contain higher levels (>0.1%) of this substance X, but because the final content of that substance must be calculated in respect to the complete article it can very well be that the concentration at article level is still <0.1%

Figure 5-2: Material breakdown of an integrated circuit[92]

5.2 REACH

The REACH regulation contains 849 pages and is one of the most complex regulations in the European Union that came into force since the last 20 years. The intention of this legislation is to unite different legislations into one. Nowadays, about 2-3 million substances are used and this vast amount has to be regulated from ecological point of view. The two considered ecological points are the human health and the protection of the environment, by providing no disadvantages for companies in international competition. The great novelty is that the authorities switched the responsibility for the declaration of their materials to the companies. The REACH was first introduced by the

[91] Cf. Philips (2011a), p. 14
[92] Philips (2011a), p. 13

European Union in 2007 and the amount of material that has to be registered is tightening in stages until 2018.[93]

The range of the REACH includes manufactured and imported goods. In the first phase a substance has to be registered if it is used over 1000tons/per anno. By 2013 the weight that is required to be registered is 100 tons/p.a. and by 2018 1 tons/p.a. The REACH Commission expects approximately 30.000 registered substances. The deadlines of the phases are as shown in figure 5-1.[94]

The Registration can be divided into the old substances and substances of very high concern (SVHC, >1500 substances and 500-1000 are relevant for Philips). The SVHC can be split up as follows:[95]

- CMR Cat. 1, 2 (carcinogenic, mutagenic or reprotoxic)
- PBTs (Persistent, Bioaccumulative and Toxic)
- vPvBs (very Persistent, very Bioaccumulative)
- Substances for which there is scientific evidence of probable serious effects to human health or environment e.g. Endocrine disrupters (affect hormone system)

On the contrary to normal substances, the SVHC has to be registered above 1 tons/p.a. and if the substance is more than 0.1% of weight of an article.

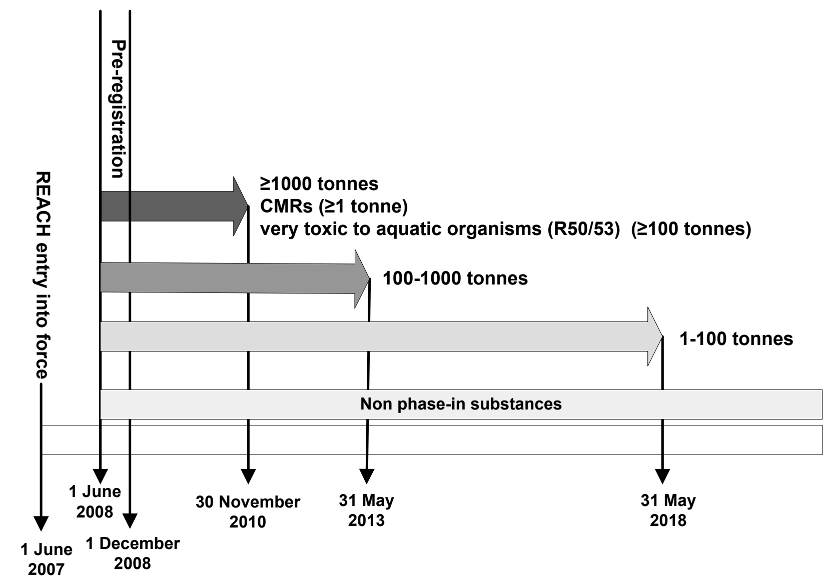


Figure 5-3: Registration Deadlines[96]

[93] Cf. European Commission Environment Directorate General (2007), p. 4
[94] Cf. European Commission Environment Directorate General (2007), pp. 6
[95] Philips (2010d), slide 6
[96] European Commission Environment Directorate General (2007), p. 9

The United States also plans a legislation like the REACH with nearly the same content. This Regulation will be an update to the Toxic Substances Control Act (TSCA).[97]

5.3 RoHS

The directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment, commonly known as Restriction of Hazardous Substances came into force 23 February 2003. The RoHS is a European directive with the objective to prohibit the use of six materials. In addition, there are penalties for companies that do not meet the directive. In accordance with article 4/1 of the official European directive, "all member states shall ensure, from 1 July 2006, that new electrical and electronic equipment put on market does not contain Lead, Mercury, Cadmium, Hexavalent chromium, Poly-brominated biphenyls (PBB) and Poly-brominated diphenyl esters (PBDE).[98]

The next Table 5-1 shows the permitted concentrations of the homogenous restricted substances.

Substances	**Maximum Concentration Limit ppm (mg/kg)**
Cadmium and Cadmium compounds	100
Hexavalent Chromium (Cr 6+) and Cr (6+) compounds	1000
Lead and Lead compounds	1000
Mercury and Mercury compounds	1000
Polybrominated diphenyl ethers (PBDEs)	1000
Polybrominated biphenyls (PBBs)	1000

Table 5-1: Permitted RoHS Concentration Limits[99]

Some of these concentrations could be higher for special purposes. These exceptions are among others: mercury in lamps, lead as an alloying ingredient for steel.[100]

The RoHS is closely connected to WEEE (Waste Electrical and Electronic Equipment). The WEEE restricts the use of hazardous material and in addition promotes the collection and recycling of old electrical and electronic waste.[101]

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97 Cf. Esty/Simmons (2011), pp. 389
98 Cf. DIRECTIVE 2002/95/EC (2003), pp. 19
99 DIRECTIVE 2011/65/EU (2011), p. 100
100 Cf. DIRECTIVE 2011/65/EU (2011), pp. 101

The EU ROHS has nothing in common with the China RoHS, Korea RoHS, Japan RoHS or any other RoHS. These directives completely differ from the EU RoHS.[102]

5.4 Philips Regulated Substances List

The Philips Regulated Substances List (RSL), formally known as Philips List of Restricted Substances, contains substances, which have not to be used in any case. Philips requires that all products, packaging, transportation and material comply with this list. The list is based on substances:[103]

which are

- banned by law or by Philips
- whose use need to be monitored due to regulatory requirements or
- whose use Philips wants to monitor from a precautionary point of view.

The introduction of REACH changed the working methods, how to collect the necessary data. Therefore, Philips has developed a system (BOM check) for the declaration of the substances. In addition, Philips asks its suppliers to enter data into BOM Check. The BOM Check standardized the collection of data.

The procedure of the application of RSL is as follows. All information about the used substances is gathered with the help of BOM Check and the supplier only has to check if the concentration is lower than required. The maximum thresholds are:[104]

- Maximum concentration limit for restricted substances
  An example of such a regulation is the RoHS. If a product or a part of the package has a higher concentration, (measured at the homogenous level) then it is prohibited. Philips accepts a certain amount of banned substances if they arise naturally.
- Maximum concentration limit for declarable substances
  The concentration of declarable substances must be monitored. The monitoring is required due to the regulations (e.g. REACH SVHCs). The use of these substances is generally permitted, but you need to report the authorities if these substances exceed a limit. The concentration is calculated on the article level.

[101] Cf. European Union, Accessed: 21.10.2011
[102] DeCusatis (2008), p. 463
[103] Philips Chemical Management, Accessed: 21.10.2011
[104] Cf. Philips (2011a), pp. 3

5.5 Future Trends and Bans

This paragraph deals with the different environmental trends in the future.

Trends in RoHS

Because a labeling of certified products is not necessary at the moment, it is possible that the next RoHS is integrated into the regulations of the CE marking.[105]

In paragraph 16 of the RoHS (June 2011, commonly known as RoHS 2.0), is stated that as soon as evidence is found of the harmful effects of nanomaterial (substances that are very small in size or with small internal or surface structure, e.g. carbon nanotubes, nano-silver particles), these will be included in the next RoHS. In addition, paragraph 10 states: some other substances are under investigation because they are potential risks to human health. These are: Hexabromocyclododecane (HBCDD), Bis (2- ethylhexyl) phthalate (DEHP), Butyl benzyl phthalate (BBP) and Dibutyl phthalate (DBP).[106]

Jill Evans, a member of the European parliament states that the following substances should be considered as well for the RoHS 3.0: Arsenic compounds, biphenyl A, beryllium and beryllium compounds, organobromine, organochlorine and flame retardants, antimony trioxide, Dinickeltrioxid flame retardants and plasticizers, carbon nanotubes and nano-silver particles.[107]

Forecast of REACH

The European government will include more substances to the old 30.000 substances. In addition, the REACH will come into force stepwise as mentioned before in this chapter.

Trends in Recycling and Packaging

The WEEE will be integrated everywhere, and the new Waste Framework directive will require the reuse of components. Take back action will increase and the companies have to understand how to use the resources that are in these discarded products.

[105] Cf. Electronics Weekly, Accessed: 20.10.2011
[106] Cf. DIRECTIVE 2011/65/EU (2011), p. 89
[107] Cf. Schubert, Accessed: 20.10.2011

The batteries of the future should contain no hazardous substances. Regarding the packaging, a reusable packaging will be necessary to avoid mountains of waste.[108]

Trends in Ecodesign

First of all energy efficiency will become a major issue in near future and there will be more regulations and specific requirements on products in terms of ecodesign. In an IPP project of market leaders it was concluded that benchmarks will be helpful to initiate voluntary changes. The next Ecodesign legislation in the European Union is called IPP (Integrated Product Policy). Besides, some social and environmental labeling of products will be expected.[109]

5.6 Conclusion

The current situation is forcing companies to abandon the use of hazardous substances. As the EU regulations are tightened up again and again, it is advisable to always be one step ahead of the regulations according to Esty/Simmons.[110]

Name	Latest release	Calculating base	Objective	Number of substances
RoHS	2011	Homogenous material	Restriction of substances	6
REACH	2009	Article base	Declaration of substances	> 30,000
RSL	2011	Article and homogenous material	Regulating the used substances in accordance with legislations	approx. 82

Table 5-2: Facts of Legislations and Compliances

[108] Cf. Wimmer et al. (2011), p. 11
[109] Cf. Wimmer et al. (2011), pp. 7
[110] Cf. Esty/Simmons (2011), p.196

6 Approaches to Achieve a Greener Product

In order to improve the environmental impact of a product, it is very helpful to use different methods upfront. The methods for assessing the environmental impact, which are discussed in chapter 4, are suitable for analyzing the product when it is already developed and indicates how to lever the sustainability. On the contrary, it is useful to influence the sustainability in product development in early stages because the cost of changes is lower, as shown in Figure 6-1.

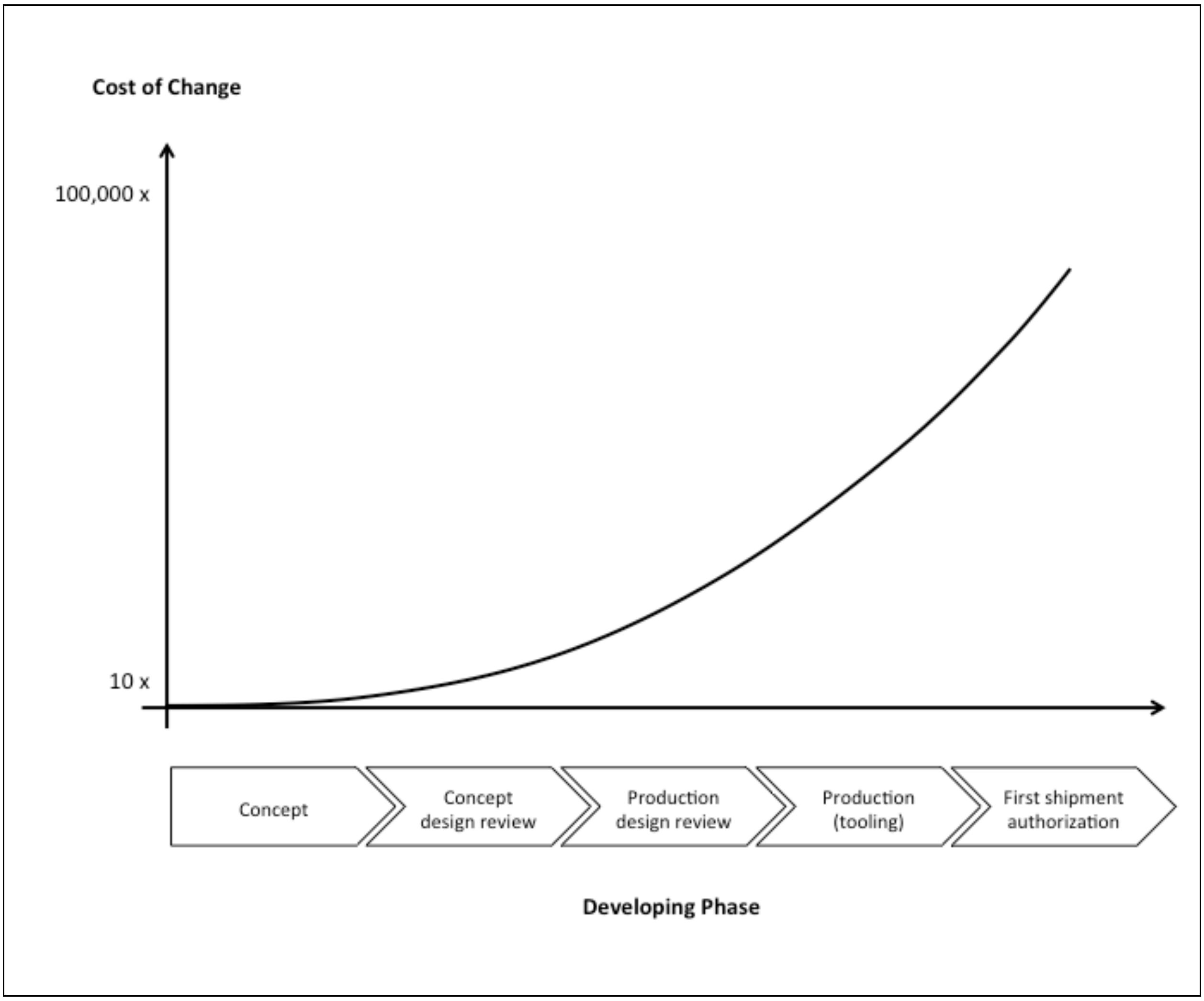

Figure 6-1: Cost of change[111]

[111] Folkestad/Johnson (2002), pp. 97

The following chapter gives an overview of methods that are commonly used for decreasing the impact, in particular the methods according to the following books:

- Cradle to Cradle written by Braungart/McDonough
- Ecodesign written by Wimmer et al.
- Green to Gold written by Esty/Simmons

Based on these approaches, the best fitting design rules are then united in a set of design rules in chapter 8.

6.1 Cradle to Cradle

In 2002 Braungart and McDonough released the first edition of the book Cradle to Cradle: Remaking the Way We Make Things. This book does not pursue the old cradle-to-grave approach, but attempts to introduce a new way of thinking called cradle-to-cradle (C2C). C2C is a model that is biology-inspired. The model describes industry with the help of biological processes by replacing materials with nutrients.

6.1.1 Principles of Cradle to Cradle

The approach of C2C is based on the following principles, which are all linked and cannot exist without the other. C2C principles are taken from the presentation Introduction to the cradle-to-cradle design:[112]

- Waste equals food
    - Everything is a raw material-nutrient for something else
    - Product use-scenario is defined
    - Chemical content is known & defined
    - Materials are safe for humans and environment in use-scenario
    - Products are designed for flowing in loops – recyclable or biodegradable depending on use-scenario
    - Products are taken back & recycled or biodegraded

[112] Philips (2011b), slide 6 et seq.

- Use solar income
    - All energy used for production, use and recycling is based on direct and indirect energy from the sun
    - Geothermal or gravitational energy are just as good
    - All materials used for solar panels, wind turbines, etc. are also applying the principle Waste Equals Food
    - Use breakthrough efficiency to support adoption of renewable energy
    - Fossil (oil and natural gas) and nuclear based energy are not considered because they are not CURRENT solar income
- Celebrate diversity
    - The work site offers new habitats for local species
    - The product or the production process has a beneficial impact on humans and the environment
    - All people have equal rights regardless of age, sex, color, abilities, religion, location, finances, etc.
    - The creativity of people is fostered
    - Create and consider multiple solutions
    - Integrate different knowledge to create something new
    - Share good ideas globally

6.1.2 Nutrient Cycles

All material flows can be divided into two cycles, biological cycle and technical cycle. On one hand products can be designed that are made from biodegradable material and can be integrated into biological cycle. Biodegradable materials could decompose and return biological nutrients to the soil. These products for consumption are a for example: packaging, shampoo bottles, toothpaste tubes, and so on. The products of the biological cycle are short-lived products. On the other hand you can design products, which are made of technical material and should stay in the closed technical cycle. The technical materials continually circulate in the technical cycle as nutrient of it. The products of the technical cycle are called products for service and are durable products with long lifetime. They contain valuable technical nutrients. The Figure 6-2 illustrates the above-described cycles with each life cycle stage.[113]

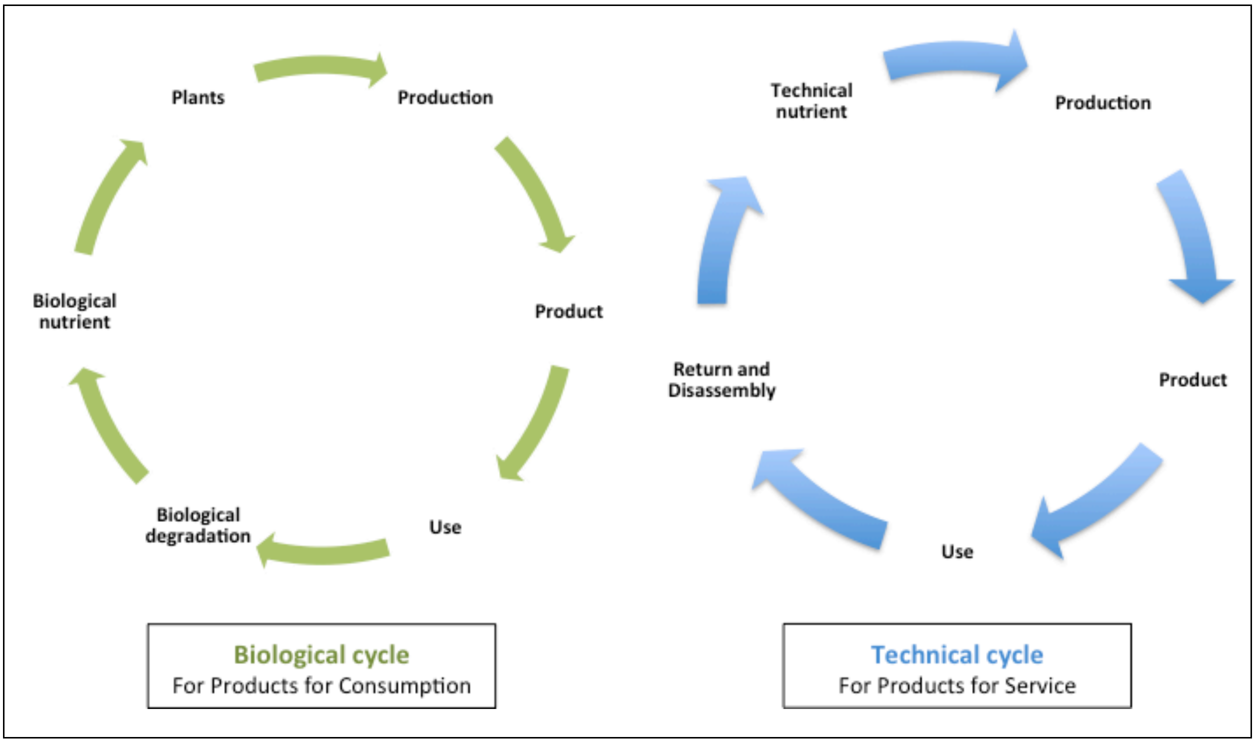

Figure 6-2: Technical and biological cycle[114]

6.1.3 Recycling, Downcycling, Upcycling

What is recycling? Actually recycling is to downcycle the material, because the recycled materials certainly do not provide the same properties as virgin material. The decreasing properties are elasticity, clarity and tensile strength that will suffer without putting in some new additives. Considering this issue, some critical thinkers will come up with the question: Is this really green or sustainable to attain a material filled with additional additives?[115]

Instead of practicing recycling, use upcycling like Henry Ford: He shipped the Model A in crates and used this crate as a floorboard when they reached its destination. Obviously, upcycling gives the waste a function and a value during the use stage.[116]

[113] Cf. Braungart/McDonough (2009), pp. 27
[114] EPEA Hamburg, Accessed: 26.10.2011
[115] Cf. Braungart/McDonough (2009), p. 56
[116] Cf. Braungart/McDonough (2009), p. 110

The authors mention one quote from Lilienfield/Rathje that brings the term recycling to the point: *"The best way to reduce any environmental impact is not to recycle more, but to produce and dispose of less."*[117]

6.1.4 Concerning the Use of Materials and Substances

In terms of substances, the following questions have to be considered: Why is it in there? Is it necessary? What happens with the materials when they are recycled or mixed with other materials? What about the waste treatment of this material?[118]

Braungart/McDonough also described sustainability in terms of local networks and stated: *"All sustainability is local."*[119] When you can connect all your material and energy flows to the local network, they will become automatically sustainable. The local network will open the doors for a profitable local enterprise. Use the Hannover principles: *"Recognize interdependencies. The elements of human design are entwined with and depend upon the natural world, with broad and diverse implications at every scale. Expand design considerations and recognize distant effects."* [120]

6.1.5 Five Steps to Eco-Effectiveness

The authors investigated several companies and as a result they developed a 5- step plan to eco-effectiveness. These steps are built up on life cycle thinking and are as follows:[121]

1. Get free of known culprits
   Do not use materials that obviously harm the environment. These are called the X substances: Lead, cadmium, PVC and mercury.
2. Follow informed personal preferences
   The author mentions one story to explain this point. Consider that you invite some friends for dinner. You decided to be a vegetarian, as a personal preference and meat does not fit your "free of" strategy because it is fed with hormones. But the decision of being a vegetarian does not indicate the production of your used ingredients. Maybe you prefer organic vegetables but without the knowledge how they were produced, packed and transported. You

[117] Lilienfield/Rathje (1998), cited in Braungart/McDonough (2009), p. 50
[118] Cf. Braungart/McDonough (2009), p. 38
[119] Braungart/McDonough (2009), p. 123
[120] Braungart/McDonough (2009), p. 123
[121] Cf. Braungart/McDonough (2009), pp. 165

only know everything about your product if you produce it yourself. This little story should map out that your personal preferences for sustainability will result in more eco- effectiveness but without considering the side effects it could go in the wrong direction.

3. Create a “passive positive” list
   Consider the substances that are used in your product. Are they problematic or toxic? What is its end state? This list is separated in three different lists:
   The X List: are the problematic ones that obviously harm the environment. This should consist of the substances, which should be phased, out like: Lead, Cadmium, Mercury and PVC.
   The grey list: contains problematic substances that are not urgent to phase out.
   The P list: the positive or preferred list. There are substances that do not harm the environment and are safe for use. For example: biodegradable. The materials that are used for a product should entirely be from this list.
4. Activate the positive list
   Now the redesign starts. Create a new product with regard of the earlier developed list. Start to make this product more sustainable with the help of the p-list.
5. Reinvent
   The objective of this step is to create a product with positive emissions instead of less negative emissions.

6.2 EcoDesign

In 2011 Wimmer et al. released the book: EcoDesign: The Competitive Advantage. The improvement of the environmental impact with the EcoDesign Toolbox is the main subject of this book. EcoDesign is based on life cycle thinking, which are raw material, manufacturing, transportation, use, and end of life. The CFC method for evaluating the environmental impact described in chapter 3 is part of this book. The next paragraph deals with the evaluation of other environmental issues upfront.

6.2.1 Resource Use Efficiency Aspects

To deal with the different aspects of improving the use of resources, the authors divided the method in two parts.[122]

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[122] Cf. Wimmer et al. (2011), p. 41

First you have to calculate the recyclability of the product by dividing total weight of recycled material by the total weight. The second step is to design a greener product with the help of the following principles:[123]

- Minimize the number of plastics used. Prefer Monotype
- Avoid painting and surface treatment of external parts
- Avoid structural design that makes disassembly difficult, such as metal inserts in the plastic parts
- Identify material types when using plastic parts
- Select recyclable material
- Implement structural designs that enable easy and quick disassembly of the parts requiring frequent service, the parts with higher recycling value and those containing hazardous substances
- Minimize the number of joints such as bolts and nuts, and ensure that disassembly can be done through the use of regular and readily available tools.

Define a matrix (as indicated in Table 6-1) to evaluate the impact of your action in terms of the principles as mentioned above and score the impact with a scale from 0 to 3. It is also possible to implement a weight for each sub category. As a result the calculation gives a weighted value for the estimation of efficiency of resource use.[124]

[123] Wimmer et al. (2011), p. 40
[124] Cf. Wimmer et al. (2011), p. 40

Category	Sub category	Evaluation criteria	Target	Evaluation results
Product weight	Product weight	Measured weight of product, accessories, and batteries	Weight of product	Product weight, Battery weight
Recyclability	Recyclability	% Recyclability = (total weight of all recyclable parts/ product weight)×100	Large product: 75%, IT product: 65% Small product: 50% (cf. also WEEE targets[a])	% Recyclability
Easiness of recycling	Coating and painting of external plastics	% coating/painting not applied = (1−number of parts with coating and painting/number of external plastic parts) × 100	Yes or No per product	Number of parts with coating and painting
	Use of composite materials	Check the presence of composite materials used in the plastic parts exceeding 20 g weight	Yes or No per product	Parts names concerned and type of composite materials
	Number of plastics used	Plastics in the external cover and housing	Number of plastic types	Number and type
	Material name of the plastic parts identified	% identification = (number of parts identified/total number of parts considered) × 100	100% material identification	Number of parts considered Number of parts with material ID

[a]Numbers in this table are for illustrative purposes only

Table 6-1: Evaluation of product resource use efficiency[125]

[125] Wimmer et al. (2011), p. 41

6.2.2 Basic Principles

Wimmer et al mention in their book three simple principles that are easy to use for designers. These principles will help to increase the sustainability of concrete products. The basic principles are: reduction, substitution, and avoidance. The term reduction refers to use less material or to use less amount of energy or to consume less of other resource. Substitution deals with the change of material or the change of functions. Regarding to avoidance this could be described by omitting a specific part or function, which are not necessary for the product. Table 6-2 is designed for products that are use-intensive (for example TV) that means the main energy consumption occurs during the use stage and the Table 6-3 shows some ideas for products that are raw material-intensive or manufacturing-intensive (for example: epilators).[126]

Other strategies for improving the environmental impact are described in the Appendix I.

Product characteristics	Reason	Principle	Actions (examples)
Use intensive	Energy consumption	Reduce	❐ Minimize energy consumption by increasing efficiency of product
			❐ Reduce stand-by consumption
		Substitute	❐ Choose different principle of function
			❐ Make possible use of renewable energy resources at use stage
		Avoid	❐ Avoid environmentally harmful abuse of product
			❐ Avoid use of batteries
	Material consumption	Reduce	❐ Design product for minimum consumption of process materials
			❐ Concentrate wear on replaceable components of product
			❐ Make signs of wear easily visible
		Substitute	❐ Design for use of process materials from renewable raw materials
		Avoid	❐ Avoid and/or minimize waste at use stage
			❐ Close cycles for process materials needed at use stage
			❐ Provide for incentives for and possibility of collecting waste from use stage

Table 6-2: Improvement principle for use-intensive products[127]

[126] Cf. Wimmer et al. (2011), pp. 124
[127] Cf. Wimmer et al. (2011), p. 126

Product characteristics	Reason	Principle	Actions (examples)
Raw material/ manufacturing intensive	Material	Reduce	❒ Realize simple principle of functioning ❒ Reduce number of parts and components ❒ Integrate functions ❒ Aim at optimum strength ❒ Reduce packaging
		Substitute	❒ Use of materials with a view to their environmental performance ❒ Use of recycled materials ❒ Use single material components ❒ Reduce number of different materials ❒ Prefer materials from renewable raw materials ❒ Prefer recyclable materials
		Avoid	❒ Avoid the use of new material by reusing parts and components ❒ Avoid or reduce the use of toxic materials and components ❒ Avoid inseparable composite materials ❒ Avoid raw materials, components of problematic origin
	Process	Reduce	❒ Use energy efficient production technologies ❒ Reduce energy consumption by optimum process design ❒ Minimize overall energy consumption of production site
		Substitute	❒ Preferably use renewable energy resources ❒ Preferably use process materials from renewable raw materials ❒ Use environmentally acceptable auxiliary and process materials
		Avoid	❒ Avoid production waste and recycle process materials whenever possible ❒ Avoid environmentally hazardous production technologies *and materials*

Table 6-3: Improvement principle for raw material/manufacturing- intensive products[128]

[128] Wimmer et al. (2011), p. 127

6.3 Green to Gold

The book "Green to Gold: Business Playbook, How to Implement Sustainability Practices for Bottom-Line Results in Every Business Function",Esty/Simmons is a kind of practical encyclopedia that describes sustainability for each area of companies. Moreover, it provides for each area (product development, manufacturing, services, logistics and transport and etc.) approaches to significantly improve the sustainability. To achieve a better performance, the following principles will help, according to Esty/Simmons.[129]

- Set Dematerialization and reduced energy use goals
  - Reduce the material that is used in the product and also the energy consumption, by using a LCA to figure out the triggers of the product you want to improve.
- Use Green Chemistry
  - To rethink the used material and to use materials, that does not harm the human health and lower the environmental impact.
  - Utilize green and black lists, it is helpful to create a list that contains the preferred material and the other one should be the material to avoid.
- Design ahead of regulation. Some regulation like REACH forces companies to declare their substances.
- Separate Design for the Environment Options
  - Design for recycling, to build a product that is easy to recycle, besides create a product that can be disassembled with for example 6 screws.
  - Design for reconditioning,
  - Design for longer life, it is sustainable to create durable goods that last for a longer period.
- Look to the nature for Inspiration
  - Biomimicry, Innovation Inspired by Nature, This concept was published by Janine Benyus; it might be useful to look to the nature to solve the ecological problems. For example: Boeing adopted the wings of bats and dragonflies for their winglets and reduced the air resistance for lower energy consumption.

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[129] Cf. Esty/Simmons (2011), pp. 194

- Servicize your product
  - For example: FedEx used the servicization of their product by not delivering a mail via transport, but to send an email to the closest delivery store then print it there and deliver the mail to its destination. As a result the saved many transport costs and also the lower their carbon emission.

6.4 Conclusion

Nowadays, many principles are out there, but commonly used ones were described above. In short, all mentioned methods could be summarized with the basic principles of Wimmer et al.: reduction, substitution, and avoidance. Obviously, if the product designers attempt these principles during the development of a new product, the result will be a more sustainable product.

Name	Authors	Based on	Important principles
Cradle to Cradle	Braungart/McDonough	Bio-inspired	Principles of C2C * Waste equals food * Use solar Income * Celebrate diversity Considering nutrient cycle * Biological cycle (products for consumption) * Technical cycle (Products for services) Apply the five steps to eco-effectiveness 1. Get free of known culprits 2. Follow informed personal preferences 3. Create a “passive positive” list 4. Activate the positive list 5. Reinvent
Ecodesign	Wimmer et al.	Lifecycle thinking	Basic Principles * Reduction * Avoidance * Substitution
Green to Gold	Esty/Simmons	Best practices	Principles * Set Dematerialization and reduced energy use goals * Use Green Chemistry * Design ahead of regulation * Separate Design for the Environment Options * Look to the nature for Inspiration * Servicize your product

Table 6-4: Summary of the approaches

7 Investigation of Alternative Materials

In order to lower the environmental impact of products one possible solution will be to substitute the fossilbased material with biobased material, in particular biodegradable material. Regarding to Michael Braungart and William McDonough's approach in Cradle-to-Cradle, recycled material does not solve the problem of creating a sustainable product. They stated that recycling materials only delays the problem without solving it and as a result they prefer biodegradable material.[130]

The next Figure 7-1 shows the word-wide and European production of plastics since 1950. The increasing oil price will force companies to consider biobased materials for their products because of direct dependency of plastics on oil. This is a great chance for biobased material.

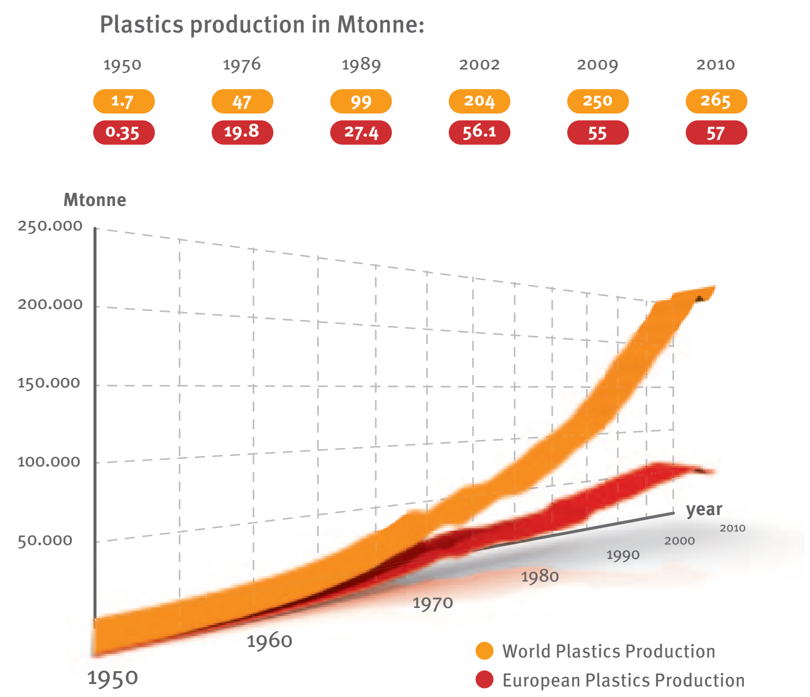

Figure 7-1: World-wide and European production of plastics since 1950[131]

[130] Cf. Philips (2011b), slide 3
[131] PlasticsEurope (2011), p. 6

This chapter starts with some general facts on biobased material, followed by a detailed description of selected biobased material. In addition, the results of short investigation of recycled material are described in chapter 7.2.

7.1 Biobased Material in General

The following chapter describes several general facts on biobased material in detail. It starts with the definition of biobased material and it is followed by an overview of biobased material. This chapter includes a classification of this material in terms of its raw material. The last part covers detailed information of several biobased materials. These are:

- Polylactic Acid PLA
- Polyhydroxyalkanoates PHA
- Wood Plastics Composites WPC
- Bio- Polyamide PA (nylon)
- Cellulose Polymers

7.1.1 Definition of Biobased Material

The commonly used definition for biobased material was published by the American Society for Testing and Materials (ASTM).

"biobased material as organic material in which carbon is derived on renewable resource via biological processes. Biobased materials include all plant and animal mass derived from carbon dioxide recently fixed via photosynthesis, per definition of a renewable resource."[132]

This definition does not indicate whether the material is biodegradable or entirely based on renewable resources. Fossilbased materials that are combined with renewable resources also comply with this as well.

[132] ASTM: American Society for Testing and Materials D6866

7.1.2 Overview of Biobased Material

The following Figure 7-2 gives an overview of all biobased materials and divides the materials into its features like biodegradability and biobased content.

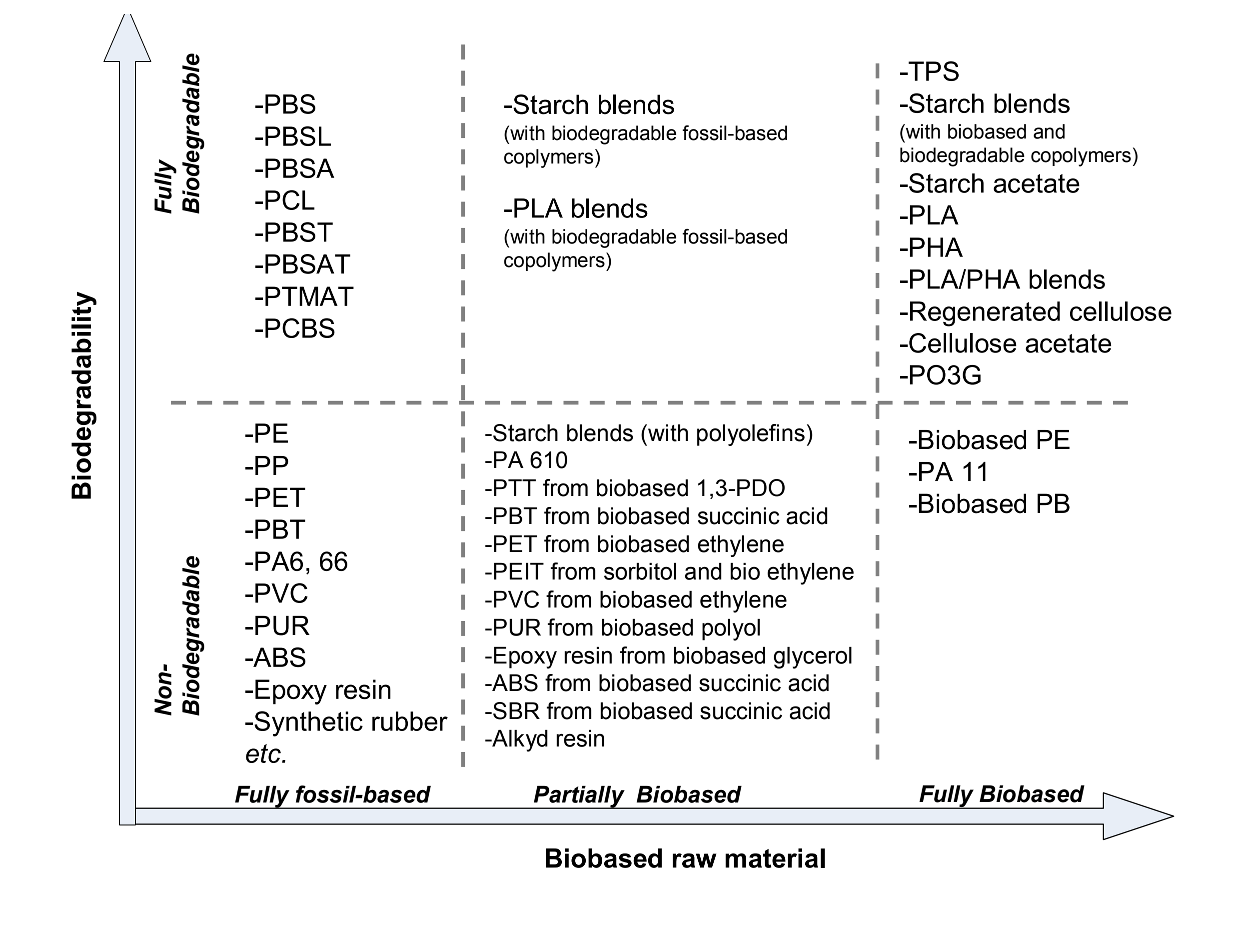

Figure 7-2: Overview of Biobased Material[133]

The section of Figure 7-2 with the highest attention for the investigation is on the top right side. All mentioned materials there ars fully biobased and fully biodegradable. In terms of maturity the most common ones are the PLA, cellulose acetate and the PHA. These materials have the potential to substitute fossilbased material and meet the requirements of consumer goods.

As shown in chapter 8, the fossilbased materials, which should be replaced by a biobased materials include: ABS, transparent PC and POM. After a search of various biobased materials following materials were found as a substitution. These are: PLA, PHA / PHB, wood compound, PA, and cellulose acetates.

[133] Li Shen et al. (2009), p. 10

7.1.3 Classes of Bioplastics

Busch developed a classification for bioplastics, based on four categories. These categories are based on the respective plant raw material. [134]

- Sugar and starch- based bioproducts are derived from sugarcane, sugar beets, corn, wheat, rice, potatoes, barley, grain, and wood through fermentation and thermochemical processes.
- Oil and lipid-based bioproducts are derived from soy, canola, sunflower, or other oil seeds and include mainly fatty acids, oils, glycerine, and a variety of vegetable oils.
- Cellulose derivatives, fibers, and plastics include products that are derived from cellulose, including cellulose acetates (cellophane) and other cellulose derivatives.
- Wood chemicals are derived from trees and include tall oil, alkyd resins, rosins, pitch, fatty acids, lignin, and turpentine.

7.1.4 Polylactic Acid PLA

Polylactic Acid PLA is the frontrunner of all bioplastics and is very mature. In 1950, a Japanese company started the first commercial PLA production. Almost all PLA is produced with the help of fermentation. The glucose is fermented into monomeric lactic acid. Two molecules are then condensed to dimer lactide, which is polymerized by a ring opening to PLA in the presence of a catalyst.[135] As a feedstock many companies use maize due to the low price.[136]

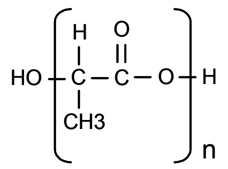

Figure 7-3: PLA molecule[137]

[134] Busch (2011), pp. 172
[135] Cf. Busch (2011), p. 174
[136] Cf. Li Shen et al. (2009), p. 71
[137] Li Shen et al. (2009), p. 97

The chemical equation of the PLAs synthesis is as follows:

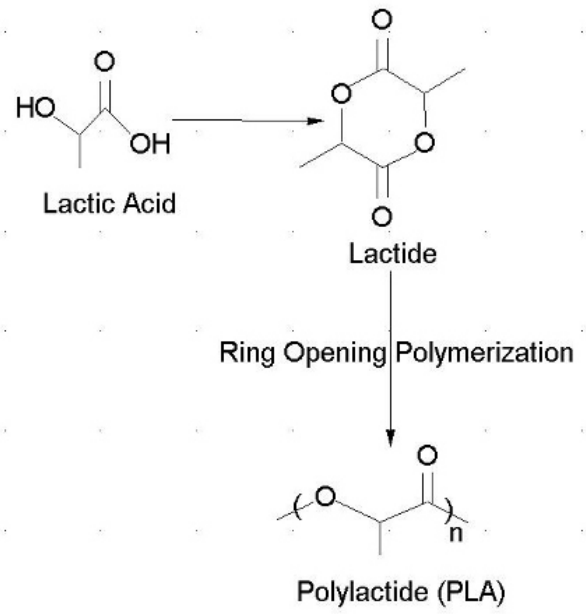

Figure 7-4: Synthesis of PLA[138]

PLA has a very high substitution potential for fossilbased plastics, due to its similar mechanical and physical properties. This bioplastic shows same characteristics in the following properties: mechanical strength, elastic recovery and heat sealability. In addition to the mechanical properties, this material also has other features like: biodegradability and dyeability.[139]

As an indication of PLA the next Table 7-1 displays some polymer types with their mechanical properties suited for different applications.

[138] Polylacitde Chemvista
[139] Cf. Li Shen et al. (2009), pp. 57

Used in the application[a]	Sheet Extrusion	Injection Moulding	Oriented Film		Blow moulded Bottles	
Polymer type	2002D polymer	3015D resin	4032D film	4042D film	7000D Bottle	7032D bottle
Density, g/cm^3	1.24 [b]	1.25 [b]	1.24[c]	1.24[c]	1.24 [b]	1.24[b]
Melt flow rate, g/10 min (210^{o}C/2.16 kg) [d]	5-7	10-25	- [m]	-	5-15	5-15
Colour	Transp.	Transp.	-	-	-	-
Haze[e]	-	-	2.1%	2.1%	-	-
Gloss, 20^o [e]	-	-	90	90	-	-
T_g. ^{o}C	-	55-65[f]	-	135 [g]	55-60 [f]	55-60 [f]
T_m, ^{o}C	Amorphous, no T_m	150-165 [g]	160 [e]	150 [e]	145-155 [g]	160 [g]
Tensile strength @ break, MPa	53 [h]	48 [i]	103 (MD)[h] 144 (TD)[h]	110 (MD)[h] 144 (TD)[h]	-	-
Tensile Modulus, GPa	3.5 [h]	-	3.4(MD)[h] 3.8 (TD)[h]	3.3 (MD)[h] 3.9 (TD)[h]	-	-
Tensile Elongation, %	6.0 [h]	2.5 [i]	180 (MD)[h] 100 (TD)[h]	160 (MD)[h] 100 (TD)[h]	-	-
Flexural Strength, MPa	-	83 [j]	-	-	-	-
Flexural Modulus, MPa	-	3828 [j]	-	-	-	-
Transmission rates						
O_2 (cc-mil/m^2/24h atm)	-	-	550[k]	550[k]	-	550[k]
CO_2 (cc-mil/m^2/24h atm)	-	-	3000[k]	3000[k]	-	3000[k]
Water vapour (g-mil/m^2/24h atm)	-	-	325[l]	325[l]	-	325[l]

[a] Refer to NatureWorks® PLA processing guide (sheet exctrusion, injection moulding, oriented film extrusion and blow moulding). [b] Testing method: ASTM D792; [c] Testing method: ASTM1505; [d] Testing method: ASTM D1238; [e] Testing method: ASTM 1003; [f] Testing method: ASTM D3417; [g] Testing method: ASTM D3418; [h] Testing method: ASTM D882; **MD** means polymer orientation in machine direction; **TD** means polymer orientation in transverse direction; [i] Testing method: ASTM D638; [j] Testing method: ASTM D790; [k] Testing method: ASTM D1434; [l] Testing method: ASTM E96; [m] data not available, not reported or not applicable.

Table 7-1: Properties of NatureWorks PLA Polymers[140]

In terms of transparent quality, PLA originally is high crystalline and can become transparent, for example, with clarifies in PP. Regarding several mechanical properties, like hardness, stiffness, impact strength and elasticity, PLA can be compared with PET. In addition, this bioplastic offers a very good UV resistance. PLA highly resists to grease and oil. For storing PLA pellets it is recommended to be very careful because PLA is more hydroscopic (water absorbing) than PP pellets. Besides the PLA can be treated on the surface with printing, metallizing and dying (also possible to use natural dye and pigmenting). PE and PP are worse to print compared with PLA.[141]

PLA provides the opportunity to get mixed with other polymers as copolymer. The outcome of the mixed plastic increases the biobased content and on the other side it

[140] Li Shen et al. (2009), p. 62
[141] Cf. Li Shen et al. (2009), pp. 64

upholds the properties of the base plastic. Some interesting polymers are blends of PLA with natural fibers, like kenaf or flax.[142]

In regard with the technical substitution potential PLA can replace LDPE, HDPE, PP, PA, and PET. POM has high abrasion resistance for moving parts, thus it cannot be substituted with this material. The limit of PLA is that it has a lower abrasion resistance compared to PA.[143]

Nowadays PLA is successfully used for the following applications: Fujitsu offers a keyboard and a mouse made from PLA. The whole injection molded housing (incl. keys) of these input devices are made from PLA. Also Sony uses a blend of 85% PLA and 15% aliphatic for their housing of the Walkman and many mobile phone companies (for example, Nokia, Samsung, NEC etc.) are developing products with PLA.[144]

To ensure the environmental performance of PLA against fossilbased material, a LCA study was investigated. The outcome of this was that all fossilbased materials have a higher impact on environment (details are shown in Appendix VI).

7.1.5 Polyhydroxyalkanoates PHA

Polyhydroxyalkanoates, short PHA, is a family of bioplastics, which are generated with the help of bacteria. The mostly produced members of the PHA family are poly (3-hydroxybutyrate) PHB and its copolymer poly (3-hydroxybutyrate-co-hydroxyvalerate) PHB-co-HV. These materials are fully biodegradable (anaerobic and aerobic) and are very suitable for technical applications due to similar mechanical properties as polypropylene (PP).[145]

Similar to the PLA production, PHAs are also produced by a fermentation of renewable feedstock. Instead of the two-stage process of PLA, PHA is produced directly via fermentation of the carbon substrate within microorganism (bacteria). PHA is now on the edge to mass production. The feedstock depends on the geographical location, for example: United States of America use corn steep liquor, the European Union use beet sugar and Brazil use sugar cane.[146]

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[142] Cf. Li Shen et al. (2009), p. 66
[143] Cf. Li Shen et al. (2009), p. 67
[144] Cf. Li Shen et al. (2009), p. 69
[145] Cf. Fakirov/Bhattacharyya (2007), p. 717
[146] Cf. Li Shen et al. (2009), p. 97

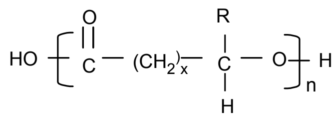

Figure 7-5: PHA molecule[147]

PHAs cannot appear transparent because of its crystalline structure. It has a high UV resistance, however the material is not resistant against acids and base. The main properties of PHAs are summarized in the following table 7-2.[148]

Product name and types	Biomer P240 [1]	Biomer P226 [1]	Mirel P1001 [2]	Mirel P1002 [2]	ENMAT [3]	Kaneka [4]	Biocycle 1000 [5]	Biocycle 2400-5 [5]	Repsol PE 077/A [6]	Hoechst G D-4755 [6]
Structure	P(3HB)		P(3HB) copolymers		P(3HB-co-3HV)	P(3HB-*co*-3HHx)	P(3HB-co-3HV)		LDPE	HDPE
Application Grade	Injection moulding	Injection moulding	Injection moulding	Injection moulding	Injection moulding	Foam moulding	Extrusion & Injection	Extrusion, injection & fibre	Extrusion & Injection	Extrusion & Injection
Physical properties										
Melt flow rate (g/10 min) at 190°C/2.16 kg	5-7	9-13				5-10	10-12	15-25	1.1	1.1
Density (g/cm^3)	1.17	1.25	1.39	1.30	1.25	1.2	1.22	1.20	0.92	0.96
Crystallinity (%)	60-70	60-70					50-60	-	40	67
Mechanical properties										
Tensile strength at yield (MPa)	18-20	24-27	28	26	36	10-20	30-40	25-30	12.4	26.5
Elongation at yield (%)	10-17	6-9	6	13	5-10	10-100	2.5-6	20-30	653	906
Tensile Modulus (GPa)					1.4		2.5-3	1.2-1.8	0.24	0.88
Flexural Strength (MPa)	17	35	46	35	61					
Flexural Modulus (GPa)			3.2	1.9	1.4	0.8-1.8				
Thermal properties										
HDT (°C)	-	-				100-110				
Melting temperature (°C)					147		170-175			
Crystallisation temp (°C)					109					
VICAT Softening point (°C)	53	96	148	137	143	120-125			93	127

Data source: [1] Biomer website (Biomer, 2008); [2] Mirel website (Telles, 2007); [3] (Lunt, 2008); [4] (Kaneka, 2007) ; [5] (PHB Industrial, 2008); [6] (Whitele *et al.*, 2000)

Table 7-2: Properties of commercialized PHAs[149]

The bioplastic PHA can fully substitute PVC, PE-HD, PE-LD and PP and partially PET, PBT, PUR and ABS. Some application areas for PHAs are: automobile carpets, dental floss, toys, and various household wares. In 2020, the estimated price of PHAs will be 3,40 €/kg.[150]

[147] Li Shen et al. (2009), p. 97
[148] Cf. Li Shen et al. (2009), pp. 102
[149] Cf. Li Shen et al. (2009), p. 105
[150] Cf. Li Shen et al. (2009), pp. 107

7.1.6 Wood Plastics Composites WPC

The WPC refers to any composite, which contains wood and plastic. The production is very simple, first the plastic is heated to admix the wood flour and then the mixture is cooled again. To improve the performance or appearance of the WPC, some additives are added to the WPC. As plastic PVC, PE, and PP is used because it keeps the price of the final product low. Also an interesting combination is wood, PP and PLA. The normal percentage of wood is between 30 and 60% and influences the mechanical properties. The commonly used wood is pine, maple, oak, and kenaf. [151]

The next Table 7-3 illustrates the mechanical properties of WPC from FKUR.

Company		FKUR	FKUR	FKUR
Product Name		Fibrolon P 7550	Fibrolon P 8530	Fibrolon P 8540
Material		PP + Wood fibres	PLA + PP + Wood fibres	PP + Wood fibres
Young's Modulus in MPa	ISO 527	3250	3800	3400
Yield strain in MPa	ISO 527	3	3,4	3
Elongation at break in %	ISO 527	22	3,8	4,5
Charpy impact unnotched 23C in kJ/m2	ISO 179-1/1 eA	7,9	11,7	11
Charpy impact notched 23C in kJ/m2	ISO 179-1/1 eU	3,3	4,8	3,6
Melt Flow Index in g/10 min	ISO 1133	13 - 15	9 - 11	2 - 3
Natural color		brownish	brownish	brownish

Table 7-3: Mechanical Properties of WPC[152]

7.1.7 Bio-Polyamide PA (nylon)

In 1930, DuPont introduced the first polyamide, which was fossilbased. A typical feature of the long-chains polyamide thermoplastics is the integrated (-CONH-) groups. The material can be processed either with extrusion or injection molding. The PA is used in automotive sector, electrical and electronic domain, packaging, and construction. Originally, the PAs are fossilbased and are named, PA 6, PA 6.6, PA 6.12, and PA 12. Regarding biobased PA, the most common biobased ones are PA 6.10, PA 10.10, and PA 11. These materials are made from castor oil. The next Figure 7-6 vividly illustrates the oil-based and biobased PA. In addition, this figure provides an indication for price and carbon chain length.[153]

[151] Cf. Klyosov/Klesov (2007), pp. 50
[152] Cf. FKUR, Accessed: 27.10.2011
[153] Cf. Li Shen et al. (2009), pp. 86

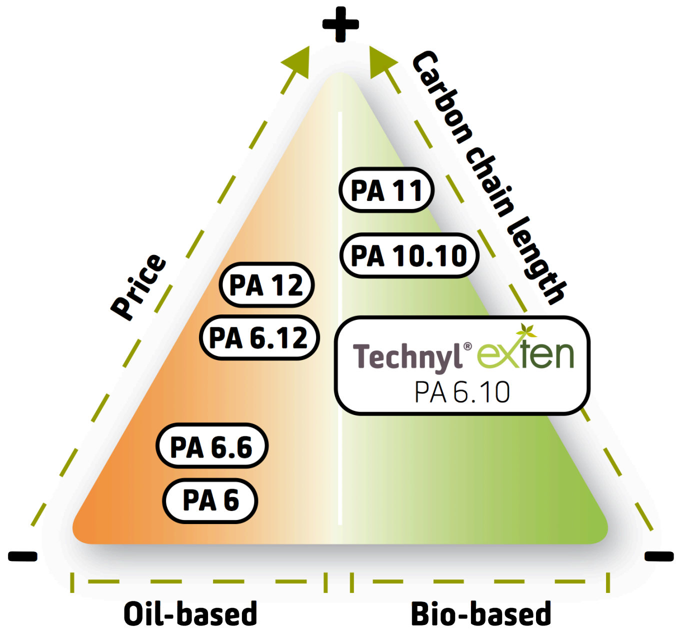

Figure 7-6: Overview biobased and oil-based PA[154]

The properties depend on the type of PA, but generally all PAs share some properties: resistance to oils and solvents; toughness; fatigue and abrasion resistance; low friction and creep; stability at elevated temperatures; fire resistance; draw ability; good appearance and good process ability. [155]

	ASTM	PA11	PA12	PA6 [b]	PA66 [b]	PA610 [d]
Density, g/cm³		**1.05** [b]	**1.02** [b]	**1.14**	**1.14**	**1.08**
Tensile strength, MPa	**D638**	**57** [b]	**49** [b]	**81**	**83**	**55**
Ultimate elongation, %	**D638**	**120** [b]	**150** [b]	**200**	**60**	**<50**
Flexural modulus, MPa	**D790**	**1170** [b]	**1410** [b]	**2700**	**2830**	**2000**
Water absorption, 24h, %	**D570**	**0.25** [b]	**0.25** [b]	**1.6**	**1.5**	**0.3**
T_g (°C)		**45**[c]	**40**[c]	**65-75**	**65-85**	**-**
T_m (°C)		**180-189**[c]	**170-179**[c]	**228**	**269**	**225**

[a] All data refer to dried polyamide.
[b] Data source: (Kohan *et al.*, 2003).
[c] The specifications of PA11 and 12 refer to Rilsan PA11 and PA12 from Arkema (Arkema, 2008a).
[d] The specifications of PA610 refer to Toray Amilan™ CM 2001 (Toray, 2008).

Table 7-4: Material properties of unmodified nylon polymers[156]

[154] Rhodia, Accessed: 28.10.2011
[155] Cf. Kohan et al. (2003), cited in Li Shen et al. (2009), p. 91
[156] Li Shen et al. (2009), p. 92

Some special properties of PA 11 are excellent dimensional stability, low-temperature toughness, and stress-crack resistance at the expense of a lower melting point and strength. PA 11 can be compared with PE in terms of its properties. [157]

Regarding to PA 6.10, this biobased PA has relatively low hygroscopic properties, good impact strength at low temperature, good dimensional stability and flex fatigue properties. [158]

Biobased PA can be seen as a 100% substitution for its fossilbased opponent.

This bioplastic has a very wide application area, for example: housings of Fujitsu laptops and mobile phones, automotive area. The price for PA 6.10 (4,32-4,73 €/kg) is 4-5 times more expensive than oil-based PA 6. [159]

7.1.8 Cellulose Polymers

Cellulose is a component that all major plants have in common. Therefore cellulose is the most occurring renewable resource. The percentage of cellulose, for example, (in wood is 40- 60% in weight and more than 90% in raw cotton.[160]

In chemical structure, cellulose and starch are very similar. The main difference lies in the combination of glucose.[161]

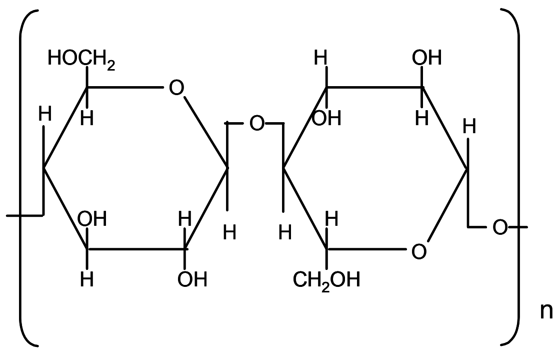

Figure 7-7: Structure of cellulose[162]

[157] Torray, Accessed: 28.10.2011
[158] BASF: Press release 2007, Accessed: 28.10.2011
[159] Cf. Li Shen et al. (2009), pp. 92
[160] Cf. Kamide (2005), p. 1
[161] Cf. Callihan/Clemmer (1979), p. 273
[162] Li Shen et al. (2009), p. 43

Depending on the production of cellulose polymers, the three main groups are used: [163]

- Cellulose esters
  - Inorganic cellulose esters (especially cellulose nitrate)
  - Organic cellulose esters (e.g. cellulose acetate)
- Cellulose ethers (e.g. carboxymethyl cellulose)
- Regenerated cellulose (e.g. cellophane and man-made cellulose fibers

However, only inorganic cellulose esters (cellulose acetate, CA) and regenerated cellulose (cellophane) are used for plastic applications. The other cellulose polymers are mainly used in application areas like: paper, cosmetics and so on. From a technical substitution perspective CAs can partially substitute PP and some types can replace PET. [164]

CA polymer is suitable for injection molding and extrusion. CA is made of cellulose esters with plasticizers up to 25%. By mixing it with the required type of plasticizer the CA polymer is determined as follows: acetate (CA), cellulose acetate propionate (CAP), cellulose acetate butyrate (CAB).[165]

According to FKuR the application areas are: electronics, household appliances, cosmetics, pens, keyboards and so on.[166]

CA reacts with acid and with alcohol because it contains a large number of hydroxyl groups. The natural appearance of CA, CAP, and CAB is crystal clear and has the properties antistatic, tough, hard, scratch resistant, insensitive to stress cracking, dye-able, but not permanently weather resistant and less suitable for precision components.[167]

7.2 Recycled Material

A short investigation of the trends in recycling plastics is reflected in this paragraph.

Approximately 24.7 million tons post consumer plastic waste was collected in Europe and 14.3 million tons were recovered. Recovering means that the plastic was either transformed into energy or recycled. The percentage of post consumer plastic for

[163] Li Shen et al. (2009), pp. 43
[164] Cf. Li Shen et al. (2009), pp. 44
[165] National Library of Australia (2000), p. 6
[166] FKuR, Accessed: 27.10.2011
[167] Cf. Rustemeyer (2003), p. 130

recovering increased 9.3% compared to 2009. The demand of European companies is estimated with 46.4 million tons. [168]

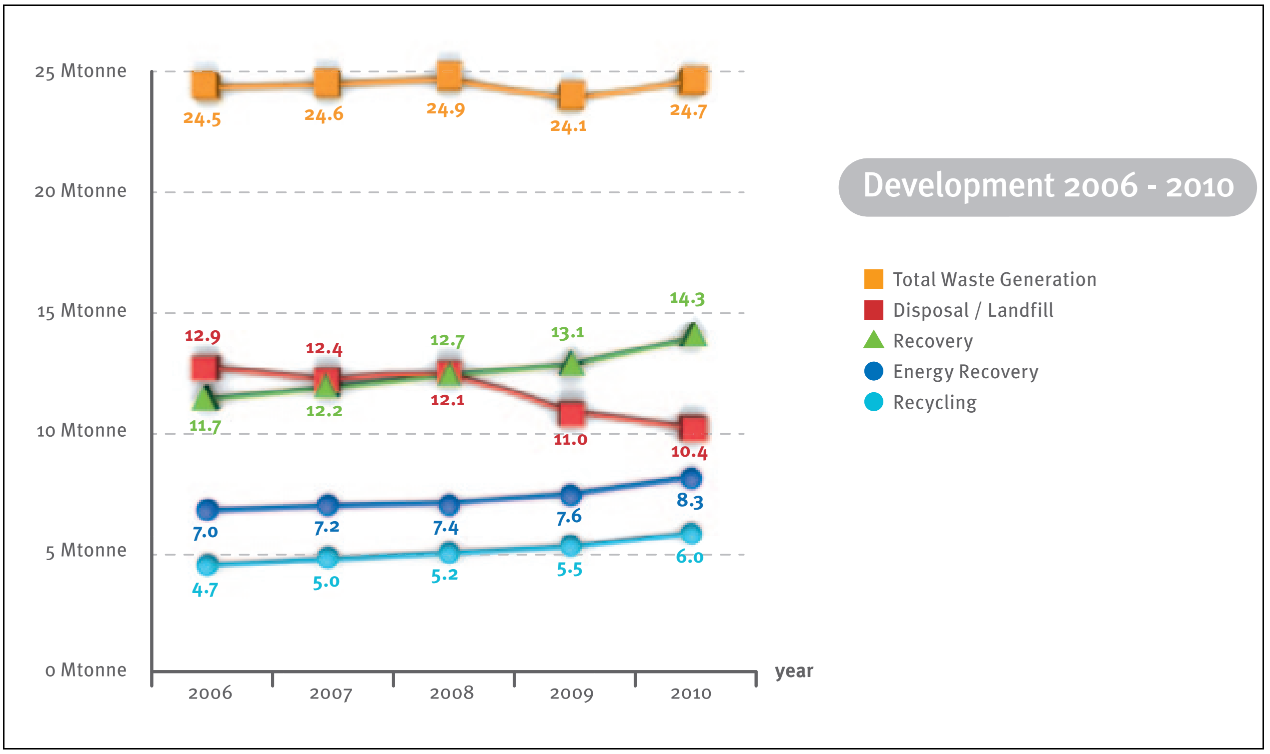

Figure 7-8: Total plastics waste recycling and recovering in Europe 2006-2010[169]

The main challenges in recycling plastic waste are the different features of the various types of plastic. In addition, one barrier is also the use of dye, fillers and additives that cannot be detected upfront. The process of plastic recycling starts by sorting the different material with the help of their resin identification code (the little triangle with the number code). If the material is not carefully sorted the recycling process could not be successful. The sorted plastic is then shredded and after this step the material is cleaned several times in order to get rid of unwanted material like paper. When the material is clean and shredded the recyclables get melted and again shredded into small-recycled resin.

In order to get some detailed information on recycled plastic from the industry, a request for information on mechanical properties, available color range, and price was sent to MBA- polymers Austria. The response was that they launch their products at the price of 70-90% of virgin material. The color is limited to dark color and post consumer

[168] Cf. PlasticsEurope (2010), p. 10
[169] PlasticsEurope (2010), p. 10

plastic can never have a bright color after recycling. The mechanical properties of recycled ABS are very close to virgin material.

7.3 Conclusion

The demand of bioplastics has increased over the past year because many companies have developed some awareness of the current environmental situation. The global demand for bioplastics will increase more than fourfold to 900.000 tons in 2013, but bioplastics will still be only 1% of the used plastics today.[170] Some companies have already implemented an action plan to integrate biobased material for their products. Also Philips has to fulfill their green product requirement and therefore especially in packaging they use biobased material. Regarding to the maturity of bioplastics, some bioplastics are very mature and ready to use as a substitution for fossil- based plastics. The main challenge for biobased material will be the price. Nowadays all bioplastics are much more expensive than fossilbased but due to more efficient technologies and a bigger production mass the price will decrease soon.

All biobased materials are made of organic raw material (except cellulose) that can be used as food. Therefore some critical thinkers state that bioplastic take away food from the poor countries. In other words many people of the world starve and some companies make plastic out of food. Currently 39% of the worldwide starch production is used for non-food application.[171] However the current numbers of the world food report from FAO state that we produce so much food to feed the double population of the world. The main problem is not the production; it is the distribution and logistics of food.[172]

[170] Cf. Lunt (2011), slide 30, Accessed: 30.10.2011
[171] Cf. Morris (2011), p. 15
[172] Cf. Ziegler (2011), p. 5

8 Translation to Philips

This chapter of the thesis deals with the combination of all above described theoretical background and translates it to Philips' products. First, this chapter focuses on the product, which has been chosen for investigation. In order to support developers guidelines, to achieve a better environmental performance were developed. Using these guidelines many ideas were generated related to the product. One of these ideas was to replace the existing fossil fuel-based material, which was examined further below. Since data from an LCA was available, these were integrated in the decision on what should be changed to the product to make it sustainable. The data can be found in Appendix II. The results of the LCA showed that the hightest improvement potential has the materials of the following parts: housing, part support (carries all electrical part inside), and transparent decor part. To perform a full LCA is not always needed and therefore the Fast Impact Assessment was developed. This tool allows the designer to make a quick statement about the material. The fossilbased materials were then replaced by biobased and investigated. Furthermore, the technical feasibility was made and a investigation of which the biobased materials had the best conditions to replace the existing material. A cost estimate carried out in these biobased materials.

8.1 The Product

The investigated product is called Satin Perfect Epilator HP 6578/00. The main function of this device is to remove hair from the skin. In order to catch the hairs, there are 32 rotating tweezers with a rotation speed of 2550 rpm. The power is 16 watts and the price of this execution (HP6578/00) is approximately 149€. This execution included: rechargeable epilator, adapter, massage attachment, comp attachment, shaver attachment, mini epilator for bikini and armpits with batteries, smart tweezers and a pouch for storage. The Figure 8-1 shows the product with all attachments.[173]

Rotating speed	2500	rpm
Tweezers	32	
Catching actions per minute	81,000	
Power	16	Watts
Price	149	Euro

Table 8-1: Key data of Satin Perfect HP 6578/00[174]

[173] Cf. Philips Satin Perfect, Accessed: 01.11.2011
[174] Cf. Philips Satin Perfect, Accessed: 01.11.2011

Figure 8-1: Satin Perfect Epilator HP 6578/00[175]

8.2 Guideline for a Greener Product

In order to develop a greener product this guideline will support you to achieve better performance in environmental assessment tools. The guideline is based on the different principles from the above-mentioned approaches in chapter 6. The combination of the principles was made with the focus on consumer goods.

1. **Always consider the whole life cycle** of your product and how you can influence it in a sustainable way. Every life cycle stage might improve the sustainability.
2. **Take a look at your used material**, is the entire chemical content known, consider following questions: Why is it in there? Is it necessary? What happens with the material if it is recycled?
3. **Use materials that are safe for humans and environment**
4. **Use green chemistry**; apply the p-list (see chapter 6.1.5) of material.
5. **Prefer biobased material**, if they do not meet the desired requirements then choose recyclable material for your product.

[175] Philips Satin Perfect, Accessed: 01.11.2011

6. **Minimize the number of plastics used**. Prefer Monotype, easier to recycle.
7. **Avoid painting and surface treatment of external parts**
8. **Reduce packaging**, use the volume ratio defined in GP definition.
9. **Design for recycling**; make it easy to disassemble the product.
10. **Think of upcycling**, for example using the packaging for transport as a guard and during the use stage as storage bag.
11. **Connect your product to the material and energy flows of the local supplier network**; all sustainability is local.
12. **Avoid structural design** that makes disassembly difficult when different materials are used, such as metal inserts in the plastic parts.
13. **Minimize the number of joints such as bolts and nuts**, and ensure that disassembly can be done through the use of regular and readily available tools.
14. **Design for a longer life**, this will decrease the environmental impact of product.
15. **Look to the nature for inspiration**; Boeing adopted the wings of bats and dragonflies for their winglets and reduced the air resistance for lower energy consumption.
16. **Offer your product partially as service**, for example, let the user read the DFU online instead of deliver the printed version.
17. **Decrease the energy consumption of the product**
18. **Design for changeability of available spare parts by the user**, provide some spare parts like the batteries in order to increase the lifetime of the product.

8.2.1 Ideas Created with the Help of the Guidelines

The above-mentioned guidelines were used to create the following ideas. Some ideas are a combination of several rules.

1.) Always consider the whole life cycle 2.) Take a look at your used material & 5.) Prefer biobased material

Considering the whole life cycle of an epilator, there will be a peak at the raw material stage. This stage consumes more energy than all other stages. As a result this is the best lever to increase the sustainability. One possible solution is to substitute the current used material with biobased material, which is discussed in chapter 8.3.

2.) Take a look at your used material

Minimize the number of parts could be realized at this product by reducing the battery wire and using a connecting strip which is directly connected to the PCB.

The current execution of the product uses four small brackets to hold the support in place. To hold the support in the desired place only three of these are required.

The top cover, which carries the décor plate made from PC, could be designed with less material because a sticker hides the top cover.

5.) Prefer biobased material, 6.) Minimize the number of plastics used, 8.) Reduce packaging & 9.) Design for recycling

The Figure 8-2 illustrates how a sustainable packaging looks like. The sustainable packaging implements several Guidelines for a Green Product. The product box and the product tray are made from paper pulp, which is completely biodegradable. The Directions For Use (DFU) and the attachments are placed under the product tray. The transparent display is made from cellulose acetate and can biodegrade as well. Moreover, when the packaging is opened, the different materials (paper bulb and cellulose acetate) get separated by itself in order to be easily deposed correctly.

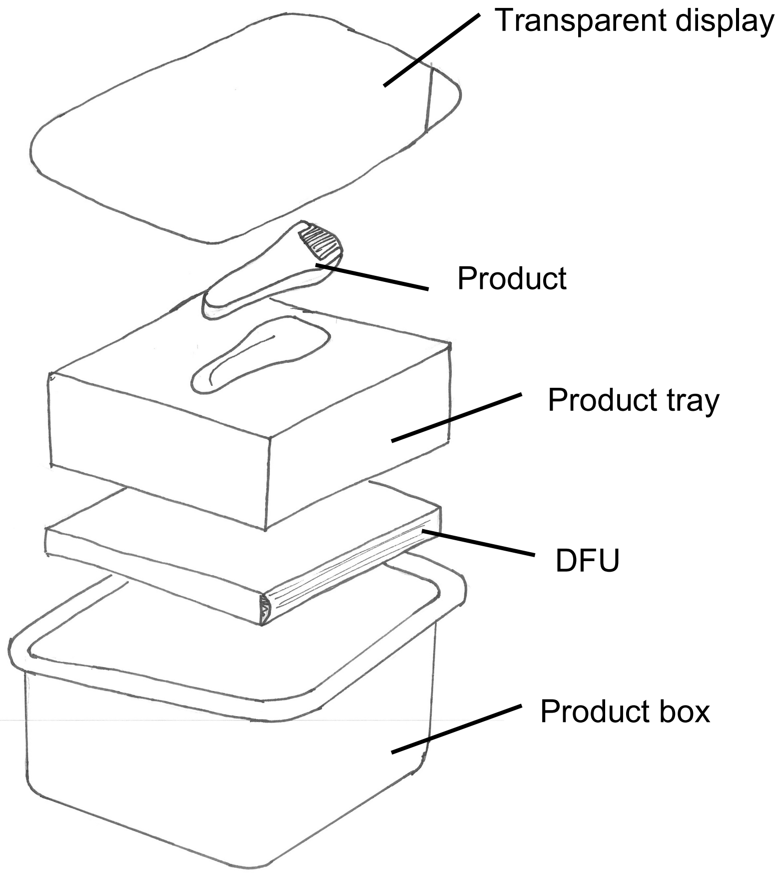

Figure 8-2: Sketch of sustainable packaging

7.) Avoid painting and surface treatment of external parts

Avoid the printing as a design element at the top décor cover.

8.) Reduce packaging

Reducing packaging could be possible with the following ideas: Use different packaging execution for indoor vendors and e-seller. This is the possibility to use a completely recycled packaging without any fancy painting, high glossy paper and so on. Therefore you could create a different very functional, sustainable-oriented packaging because the buying decision is already done. Another idea is to use a display stand for selling the products and to not use the packaging for the buying decision.

10.) Think of upcycling

In order to upcycle useless packaging, the packaging could be reused as a pouch during the use stage.

13.) Minimize the number of joints such as bolts and nuts

Design for recycling, therefore it will be useful to join the appliance with one main screw, hence the epilator can be disassembled very easily and the user is able to separate for example the batteries or the different used material for a proper waste management.

14.) Design for a longer life

To increase the lifetime of the product, it is possible to make the battery changeable.

16.) Offer your product partially as service

Servicize your product could be implemented by avoiding the delivery of a printed DFU. The consumer can read the DFU online or print the desired pages at home.

17.) Decrease the energy consumption

Regarding to the energy efficiency, the appliance should only be switched on during the epilating process. This could be realized with an automatic switch that indicates when the epilator touches the skin.

Other ideas (not guideline based)

Concerning the adapter it will be more sustainable to use an USB Cable for charging the device. These will solve two problems. First USB cables and USB Adapters are a mass product and could be reused for other appliances and the second benefit is the independence of different national sockets.

To emit less sound from the epilator, the gear can be realized as helical gear. The helical gears have the advantage to emit less sound because the teeth engage more gradually than a spur gear.

8.3 Fast Impact Assessment

The Fast Impact Assessment is an excel spreadsheet that can be of help to improve the environmental performance upfront. This tool is based on the EcoIndicator 99' values and makes it very easy to compare different materials in terms of environmental impact.

The procedure is as follows. It is only necessary to fill in the orange cells, shown in Table 8-2. First, incorporate the material type and then the amount of the material in the displayed unit. The following life cycle stages have to be filled in with the material type and weight for process data, recycled waste, and the waste treatment. The result is an EcoIndicator 99' value that represents the impact.

Fast Impact Assessment			
Production	Material	PP	
	Weight	0,05	per kg
	Ecoindicator 99	16,5	mPt
Processing	Material	Injection molding 1	
	Weight	0,05	per kg PE,PP,PS,ABS without the production of material
	Ecoindicator 99	1,05	mPt
Recycling Waste	Material	Recycling PP	
	Weight	0,01	per kg if not mixed with other plastics
	Ecoindicator 99	-2,1	mPt
Waste treatment	Material	Incineration PP	
	Weight	0,01	per kg
	Ecoindicator 99	-0,13	mPt
	Total Environmental Impact	**15,32**	**mPt**
to be filled in			

Table 8-2: Fast Impact Assessment

This tool can be the first step towards a p-list or a green list as described in chapter 6. The RSL shows developers what materials have to be avoided, but it gives no hints about what materials should be used. Therefore, it should be developed a list showing how the materials affect the environment. As a basis for determining the environmental factors a LCA data can be used. However, in order to create such a list, it is necessary to precisely to deal with the materials, which would represent its own separate task. It is highly recommended to integrate such a p-list in the development process.

8.4 Investigating Biobased Material

To replace the fossilbased material, a large number of biobased materials was investigated. The investigation was spilt up into two main parts. The first part dealt with the selection of the biobased material to come to a material that fulfils all requirements. The testing process followed the selection process in order to get a better knowledge about of the material.

8.4.1 Selection of the Biobased Material

The parts that had to be replaced with biobased material were in general housing part and inner parts of the product. The procedure of finding and selecting biobased material was as follows.

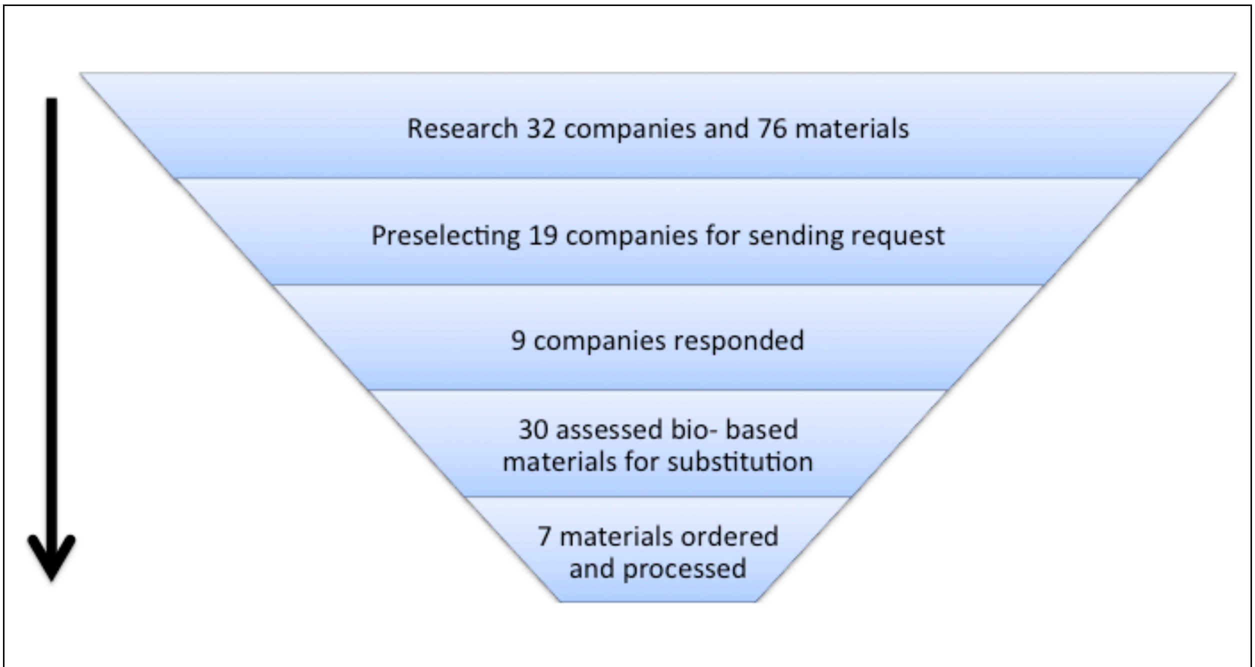

Figure 8-3: Selection process of biobased material

As a base for the market scan of biobased materials, three different sources were used. The first one was the iBIB2011: International Business Directory for Innovative Biobased Plastics and Composites[176] published by nova-institute GmBH and bioplastics magazine. The second directory was the graduation thesis of Mellema[177] on biobased materials in Senseo (coffee brewing machine for coffee pads) and the last was the homepage of European bioplastics.[178]

For the pre-selection of the companies the criteria were the size of the company (for estimating mass production capacity) and very rough mechanical properties scan. As a result of this stage, only 19 companies fulfilled the criteria and are shown in Table 8-3.

Company	Trade Name	Material	Website
Arkema	Rilsan® Clear G830 Rnew	Bio Based PA	www.arkema.com
Biocylce	189C-1/ 1000/ 189 D-1	PHB	www.biocycle.com.br
Biomer	P209, P226	PHB	www.biomer.de
Biopolymers	Solanyl	TBS	www.biopolymers.nl
FKUR	BioGrade, Fibrolon, BioFlex	Cellulose	http://www.fkur.com
Green Gran	N 026J/ F023J	WPC	www.greengran.com
Hypropolymers	Hiprolon	Bio Based PA	http://www.hipropolymers.com.cn/
Mazzuchelli	Bioceta	Cellulose	http://www.mazzucchelli1849.it
Mirel	P1003,P1004,F1005,F1006	PLA	www.mirelplastics.com
NatureWorksLLC	Biopolymer	PLA	http://www.natureworksllc.com/
PolyOne	reSound	PLA	http://www.polyone.com
Proganic	Proganic	PLA	www.proganic.de
Purac	PURALACT	PLA	www.purac.com
Tecnaro	Abroblend/Abroform	WPC	www.tecnaro.de
Albis	Cellidor	Cellulose	www.albis.com
Bayer	Makroblend BC250, BC400	PLA+PC	http://plastics.bayer.com/
DSM	EcoPaxx	Bio Based PA	www.dsm.com
Eastman	Tenite	Cellulose	www.eastman.com
Toray		PLA	http://www.toray.de/

Table 8-3: Selected companies

In order to get more information about the material, a specific request was sent to the companies and they should recommend a suitable bioplastic for the requirements in the request. Regarding to the different parts, the request was built up on five main parts of the epilator, a transparent part, three housing parts and an inner part with its requirements. The main driver of the transparent part is high visual quality. High impact

[176] Nova Insitute GmbH, Accessed: 03.11.2011
[177] Mellema (2009), pp. 11
[178] European plastics, Accessed: 03.11.2011

resistance and visual quality characterize the housing part. The inner part should have a high stiffness, but the visual quality is not as important as for the other parts. The main intention on creating this request was to gather information on recommended materials, biobased content, mechanical properties, visual properties, price, and production capacity. The request is shown in Appendix V.

9 companies responded to the request. With the help of the new information supplied the materials were assessed again. The outcome was a list (see Appendix VI) for each part with the top ranked materials. The rating was calculated as follows. The main properties were determined with their ranges and in the next step transformed into a range from 1 (very bad) to 5 (very good). This transformation of the values was needed to compare the different criteria (qualitative, for example, processability and quantitative, Young's modulus). According to this list the best seven materials, shown in Table 8-4, were ordered for testing samples in-house.

Company Name	Trade Name	Material
FKUR	BioGrade C 7500	Cellulose Acetate
FKUR	Fibrolon P 8530	PP + PLA + Wood fibres
FKUR	BioFlex S6540	PLA
Hipro	Hiprolon 200 VN	PA 10.10
Biomer	P226	PHB HV
DSM	Ecopaxx Q150D	PA 4.10
DSM	Ecopaxx Q-X70208	PA 4.10 with Glas fibres

Table 8-4: Ordered biobased materials

8.4.2 Testing the Selected Materials

Following the selection process, all the selected materials (Table 8-4) were molded. The materials were processed with an injection-molding machine using a testing shape. The testing shape is designed to determine process ability and visual quality. The samples are displayed in the following Figure 8-4 and Figure 8-5.

Figure 8-4: (from left to right) Hiprolon 200 VN, EcoPaxx Q 150D, EcoPaxx Q-X70208, BioGrade C7500,

Figure 8-5: (from left to right) BioFlex S6540, P226, and Fibrolon P8530

After processing the materials, these were evaluated again with stricter criteria and better information on processability and visual quality. The criteria for the last assessment are divided in categories: sustainability, quality requirements, economic criteria, mechanical criteria, process ability, design criteria and supplier response. If a material scores 5, it totally fulfills the criterion. The brief description shows how to calculate the scores by indicating the boundaries of the properties.

Category	Properties	Unit	Brief description	Min	Max
				1	**5**
Sustainability	Biobased Content	%	1 = < 40% 3 = 70% 5 = 100%	40%	100%
Sustainability	Not in conflict with food supply		1 = food, can be eaten, direct conflict 3 = grows on agricultural areas, but no food 5 = not in conflict means: does not grow on agricultural area and no food	1	5
Quality requirements	Material lifetime		1 = material Lifetime not acceptable 3 = restricted acceptable 5 = good mat. Lifetime expected Are there some showcases published? Are the quality requirements of these high?	1	5
Economic criteria	Price	€/kg	1 = > 15€/kg 3 = 8€/ kg 5 = 2€/kg	15	2
Economic criteria	Maturity		1 = development grade 3 = on edge to mass production 5 = serial production running	1	5
Mechanical criteria	Young's Modulus	N/mm^2	1 = <1000 MPa 3 = 2500 MPa 5= > 4000 MPa	1000	4000
Mechanical criteria	Charpy impact notched 23C	KJ/m^2	1= $2kJ/m^2$ 3= $8\ kJ/m^2$ 5= $>14kJ/m^2$	2	14
Processability			1= bad 5= good Depending on MFI, Shrinkage , temperature sensitive, demoldability:	1	5
Design criteria	Transmission grade		1 = opaque 3 = translucent 5 = transparent	1	5
Design criteria	Visual quality		1= no glossy, not homogenous surface 3= not glossy, only rough homogenous surface 5= high glossy, homogenous. Surface	1	5
Design criteria	Decoration possibilities		1= not to decoration with pad printing or lacquering 3= restricted, with pretreatment or to be tested 5= good to lacquer, hotfoilstamp	1	5
Supplier response			1= no response 5= good, comprehensive response	1	5

Table 8-5: Criteria and explanation for assessing biobased materials

The above-mentioned criteria are applied on the following data. The Table 8-6 shows the mechanical, processing, economic, and sustainability properties. These values are the base for the scoring in Table 8-7. The values of Table 8-6 are gathered from the data sheet and the request. In order to compare the biobased material with a fossilbased material, the first row of Table 8-6 shows the properties of a fossilbased material called ABS, at Philips a material for housing parts of the epilator.

Company	Product Name	Material	Biobased Content	Shrinkage	Melt Flow Index	Price	Young's Modulus	Charpy impact unnotched 23C	Charpy impact unnotched -30C	Charpy impact notched 23C	Charpy impact notched -30C
			in %	in %	in g/10min	in €/kg	in Mpa	in kJ/m“	in kJ/m“	in kJ/m“	in kJ/m“
BASF	Terluran GP-22	ABS	0	0,4-0,7	19,76		2300	180	100	26	8
FKUR	BioGrade C 7500	Cellulose Acetate	50%	0,2-0,4	11 - 15	4,3-6	3000	37	6,5	2	
DSM	Ecopaxx Q150D	PA 4.10	70%	1,64		8,5	1700	No break	No break	13	4
Hipro	Hiprolon 200 VN	PA 10.10	100%	>1,3%		10	1900			16	11
DSM	Ecopaxx Q-X70208	PA 4.10 with Glas fibres	50%	1,30-1,88		7,5	5500	85		20	14
FKUR	BioFlex S6540	PLA	50%	0,3 - 0,5	5,5-7	3,9	2800	36		3	
FKUR	Fibrolon P 8530	PLA + PP+ Wood fibres	80%	0,1-0,2	9 - 11	3,5-4	3800	11,7		4,8	
Biomer	P226	PHB HV	100%	1,3	10(2,16kg)	11,5	1900	No break	30	2,7	1,4

Table 8-6: Data of the selected material

The final assessment of the biobased materials is shown in Table 8-7. The color of the cells indicates the value (green represents: 5 and red represents 1). For having a better overview of the criteria, the most relevant ones are highlighted in yellow. The Table 8-7 displays that the best biobased material can substitute the ABS of concern.

Company	Product Name	Material	Biobased Content	Not in conflict with food supply	Quality requirements*	Price	Maturity	Young's Modulus	Charpy impact notched 23C	Processability	Transmission grade	Visual quality	Decoration possibities	Response	Sum	most relevant (yellow)
BASF	Terluran GP-22	ABS	1	5	5	5	5	3	5	5	1	5	5	5	50	29
FKUR	BioGrade C 7500	Cellulose Acetate	2	5	4	4	5	4	3	4	5	5	4	5	50	26
DSM	Ecopaxx Q150D	PA 4.10	3	5	4	3	5	3	5	4	1	5	4	5	47	27
Hipro	Hiprolon 200 VN	PA 10.10	5	5	4	2	5	2	4	4	2	5	4	4	46	26
DSM	Ecopaxx Q-X70208	PA 4.10 with GF	2	5	4	3	3	5	5	4	1	3	4	5	44	26
FKUR	BioFlex S6540	PLA	2	1	4	4	5	3	1	4	1	5	4	5	39	23
FKUR	Fibrolon P 8530	PLA + PP+ Wood fibers	4	3	4	4	1	4	1	2	1	2	4	5	35	21
Biomer	P226	PHB HV	5	1	3	2	3	2	1	2	1	3	3	4	30	18

Table 8-7: Selected and processed biobased material

The best-balanced material for substitution of the ABS of concern is BioGrade C7500, but it has one big disadvantage, which is the low biobased content. On the contrary, EcoPaxx has a higher biobased content, with almost identical properties compared to BioGrade C7500. The Hiprolon 200 VN has the highest biobased content with good other properties. Two materials showed very bad process abilities. The Fibrolon P8530 had demolding problems and was soft after processing. The second one was the P226 because big flashes occurred.

Regarding to technical feasibility the next Table 8-9 summarizes the different materials and the main advantages and disadvantages, in comparison to the ABS type, typically used by Philips for housing parts. The requirements for the technical feasibility are displayed in Table 8-8. The price is an additional requirement for all parts.

Part	Requirement
Housing	High visual quality Surface treatment possible High charpy impact value Available Colors
Transparent Housing	Transmission grade All housing requirements
Innerpart	High Young's Modulus Less dependence on color Biobased content Low creep and relaxation

Table 8-8: Requirements for the parts

Company	Product Name	Material	Advantage	Disadvantage	Compared to standard ABS	Comment
FKUR	BioGrade C 7500	Cellulose Acetate	* Suitable for housing parts (transparent, good high gloss surface) * Not in conflict with food supply * Commercially available * Acceptable mechanical properties * Good to process	* 5 Euro/ kg material costs * 50% biobased content	* Similar mechanical properties * Transparent * 3-4 times more expensive * Similar shrinkage (0,3%)	yellowish color
DSM	Ecopaxx Q150D	PA 4.10	* Suitable for housing parts (good high gloss surface) * Not in conflict with food supply * Commercially available * Good mechanical properties * Good to process * 70% biobased content	* 8,5 Euro/ kg material costs	* Similar mechanical properties * 5 times more expensive * Much higher shrinkage (1,7%)	PA made of castor
Hipro	Hiprolon 200 VN	PA 10.10	* Suitable for housing parts (transparent, good high gloss surface) * Not in conflict with food supply * Commercially available * Acceptable mechanical properties * Good to process * 100% biobased content	* 10 Euro/ kg material costs	* Similar mechanical properties * 6 times more expensive * Higher mold shrinkage (>1,3%?)	PA made of castor
DSM	Ecopaxx Q-X70208	PA 4.10 with Glass fibers	* Suitable for stiff, not visible parts (good mechanical properties, high stiffness * Not in conflict with food supply * Good to process	* 7,5Euro/ kg material costs * No high gloss surface * 50% biobased content	* No high gloss, high stiffness * Higher shrinkage (0,8-1,3%)	PA made of castor
FKUR	BioFlex S6540	PLA	* Good high gloss surface) * Commercially available * Good to process	* In conflict with food supply * Too brittle for housing parts * 50% biobased content	* Lower mechanical properties * Similar shrinkage (0,3%)	Starchbased
FKUR	Fibrolon P 8530	PLA + PP + Wood fibers	* 80% biobased content * 4Euro/ kg material cost	* Too brittle for housings * Bad to process * Only wooden appearance	* Stiffer, but less impact resistance * Only wooden appearance 2-3 times more expensive	Typical wood smell
Biomer	P226	PHB HV	* 100% biobased content	* Not suitable for housing and inner part- too brittle and difficult to process (flash) * 11,5 Euro/kg material costs	* Lower mechanical properties * Higher shrinkage (1,3%) * 6 times higher material cost	flashes!

Table 8-9: Advantages, disadvantages, and comparison to ABS

8.4.3 Comparison of Material Costs

This paragraph briefly presents the cost situation. The values of the fossil materials are derived from the current calculation of the Satin Perfect Epilator with its attachments. In this calculation the following components of the product have been omitted: bikini epilator, pouch, and adapter. Only the values of the raw materials without the master batch were used because for biobased master batch the price could not be retrieved within the timeframe given.

The selection of biobased materials represents only an indication because the material would have to be more precisely adapted to the requirements of each component. The first biobased material selection was focused on the costs with acceptable biobased content (approx. 60%). As an innerpart PA 10.10 was used for this calculation and the housing material (including transparent material) uses CA. The second selection was made with the highest possible biobased content (approx. 95%), therefore the all parts were assumed as PA 10.10 and only the transparent parts were CA.

The Table 8-10 shows the comparison of material costs. The material costs per part were calculated by the multiplication of the material weight and the material costs. The fossilbased materials cost are € 0.42 in total. The 60% biobased materials cost € 0,90 and the 95% biobased materials charge € 1.50. Furthermore the sum of the fossilbased plastics is 55% lower than the sum of the 60% biobased plastics, and absolutely calculated a difference of about € 0.48 and € 1.08 occurs. When the production costs of the whole product can be assumed with € 27.46, this costs will increase 1.8% (60% biobased content) or 4% (95% biobased content) for the whole product.

Part	Material Weight	Fossil-based Material Base Material	Fossil-based Material Material Costs	Fossil-based Material Material cost/part	Biobased Material (focus on costs) Base Material	Biobased Material (focus on costs) Material Costs	Biobased Material (focus on costs) Material cost/part	Biobased Material (focus on biobased content) Base Material	Biobased Material (focus on biobased content) Material Costs	Biobased Material (focus on biobased content) Material cost/part
	in g		€/kg	€/#		€/kg	€/#		€/kg	€/#
Housing	17,83	ABS	3,13	0,056	CA	4,30	0,077	PA 10.10	10,00	0,178
Cover	12,59	ABS	3,13	0,039	CA	4,30	0,054	PA 10.10	10,00	0,126
Panel body	15,87	ABS	1,57	0,025	CA	4,30	0,068	PA 10.10	10,00	0,159
Front panel	6,80	PC	3,22	0,022	CA	4,30	0,029	CA	4,30	0,029
Light guide	2,43	ABS	1,57	0,004	CA	4,30	0,010	PA 10.10	10,00	0,024
Light guide	2,43	PC	3,22	0,008	CA	4,30	0,010	CA	4,30	0,010
Switch knob	2,24	ABS	1,57	0,004	CA	4,30	0,010	PA 10.10	10,00	0,022
Switch knob	2,24	PC	3,22	0,007	CA	4,30	0,010	CA	4,30	0,010
Design cap	7,62	ABS	1,57	0,012	CA	4,30	0,033	PA 10.10	10,00	0,076
Sensitive cap	7,60	ABS	1,57	0,012	CA	4,30	0,033	PA 10.10	10,00	0,076
Support	15,94	POM	2,83	0,045	PA 10.10	8,50	0,135	PA 10.10	10,00	0,159
Release part	2,07	POM	2,83	0,006	PA 10.10	8,50	0,018	PA 10.10	10,00	0,021
Gear wheel 1 *	2,13	POM	2,96	0,006	PA 10.10	8,50	0,018	PA 10.10	10,00	0,021
Gear wheel 2 *	2,61	POM	2,96	0,008	PA 10.10	8,50	0,022	PA 10.10	10,00	0,026
Gear wheel 3 *	3,35	POM	2,96	0,010	PA 10.10	8,50	0,028	PA 10.10	10,00	0,034
Connecting part	1,19	POM	2,96	0,004	PA 10.10	8,50	0,010	PA 10.10	10,00	0,012
Mounting plate	5,28	POM	2,96	0,016	PA 10.10	8,50	0,045	PA 10.10	10,00	0,053
Housing shaving head	12,58	ABS	1,57	0,020	CA	4,30	0,054	PA 10.10	10,00	0,126
Support shaving head	8,23	POM	2,83	0,023	PA 10.10	8,50	0,070	PA 10.10	10,00	0,082
Excenter gearwheel	2,31	POM	2,96	0,007	PA 10.10	8,50	0,020	PA 10.10	10,00	0,023
Crowngear *	2,54	POM	2,96	0,008	PA 10.10	8,50	0,022	PA 10.10	10,00	0,025
Gearwheel 6 *	2,24	POM	2,96	0,007	PA 10.10	8,50	0,019	PA 10.10	10,00	0,022
Shaving head comb	5,27	PC	3,22	0,017	CA	4,30	0,023	CA	4,30	0,023
Straight roller	1,86	ABS	4,40	0,008	CA	4,30	0,008	PA 10.10	10,00	0,019
Pivoting frame	4,02	ABS	1,57	0,006	CA	4,30	0,017	PA 10.10	10,00	0,040
Pivoting support	4,15	ABS	1,57	0,007	CA	4,30	0,018	PA 10.10	10,00	0,042
Rolling pearl	1,18	ABS	4,40	0,005	CA	4,30	0,005	PA 10.10	10,00	0,012
Wavy roller	1,69	ABS	4,40	0,007	CA	4,30	0,007	PA 10.10	10,00	0,017
Vibration frame	4,65	PC	3,22	0,015	CA	4,30	0,020	CA	4,30	0,020
Vibration lever	0,98	POM	2,96	0,003	PA 10.10	8,50	0,008	PA 10.10	10,00	0,010
		Sum €/product:		**0,415**	**Sum €/product:**		**0,901**	**Sum €/product:**		**1,497**

* these technical plastic parts need further investigation, only estimated biobased material

Table 8-10: Cost calculation of biobased materials and fossilbased materials

8.5 Conclusion

The guidelines for a greener product assist product developer for considering environmental issues at a step of development that much freedom to maneuver is still given. Therefore it is highly recommended to implement such guidelines to improve the environmental impact.

Regarding the biobased material, only a few companies produce biobased materiel compared to the huge number of companies that produce fossilbased material. But with the increased attention on sustainable development, it can be expected that this number as well as the price of biobased material will change positively in the near future. Based on the material investigation done, some of these biobased materials really have the potential and the maturity to fully replace fossilbased ones. This will further support their application in future.

9 Conclusion and Prospects

The definition of sustainability is not trivial and can usually be described only in very general terms, which makes a very specific definition difficult. Nevertheless Philips has created with its EcoVision a very good base to work on relevant sustainability aspects. Furthermore Philips provides plain information for their employees.

Regarding the different assessment tools it is certainly worth to apply them in practice. Depending on the application, it should be well considered what tool to use. It makes no sense to try to carry out an LCA in the early stages of product development because the parameters of the finished product are not determined at that time. The new Philips Green Product definition provides a well applicable tool to quickly review the environmental performance of the developed product.

The influence of the NGOs on the public opinion is increasing more and more and it becomes necessary to cooperate with them. As the requirements on the company are tightening, it is important to keep a constant eye on their programs. In particular Greenpeace has made appearance with its Guide to Greener Electronics program. It is important to keep the websites up to date because the scores of this program are based on data received from the website of the companies.

Especially in the European Union, the number of legislations regarding declaration and restriction of substances has tightened. Due to REACH, more than 30,000 different substances have to be declared. In addition, it is already thought about a new RoHS, which contains more banned substances in turn. To avoid non-compliance the regulations, it is highly important to be aware of future regulations that are currently in draft status.

It is extremely useful for product developers to take as early as possible ecological aspects into consideration. Some of these approaches can be applied even in the early stage of a product, which increases sustainability. To support the further development process, the Fast Impact Assessment and Guideline to Achieve a Greener Product were developed during this paper. The Fast Impact Assessment will help developers to come to a very fast and indicative statement of the material, which are used used and should represent a kind of p-list (see chapter 6). The Guideline to Achieve a Greener Product is a selection and adaption of rules from the books Cradle to Cradle, Green to Gold and EcoDesign.

The investigation of biobased materials carried out a selection of biobased materials that have potential to replace existing fossilbased plastics in an epilator. The inner part, the housing and the transparent part were replaced, because they have the biggest impact on the environment according to a LCA. A market research was performed and the biobased materials, which are found, were then evaluated. The subsequent request was sent out to suppliers and producers including several criteria to be satisfied. The answers to this request were integrated for the further selection. Finally seven materials complied with the requirements and they were processed and tested in-house. With the knowledge of processing these seven materials, they were evaluated once again. The result was the biobased material with the highest substitution potential, called Cellulose Acetate, has the ability to fully replace fossilbased materials.

After the investigation of the technical requirements, a brief cost calculation was done. This compares fossilbased materials with two different selections of biobased materials. One selection had the focus on material costs and therefore the biobased content was 60%. The other selection had a biobased content of 95%. The result of the calculation showed that the material costs of biobased materials depend on biobased content. This means the higher the price the higher is the biobased content. Furthermore the calculation indicated that the total costs per product will only be increased in 1.8% (60% biobased content) or 4% (100% biobased content).

Nowadays biobased materials can already be taken as a substitute for standard materials. There is no doubt that the biobased market is steadily rising. Many products of other companies, which already use biobased materials, show these ecologically friendly materials are very mature for use in consumer products. Only two questions are still open: how do we deal with the challenge of ethnic respect of eatable raw materials? How big is the price ratio compared to fossilbased materials? In the future the amount of biobased materials will increase and the price will decrease as a consequence.

Regarding to the prospects, one further step should be to create a whole product out of biobased materials and test it with the quality requirements. The transport and the electronics are also major levers to lower the impact on the environment, but these two points were not in the scope of this thesis. The Fast Impact Assessment needs some further investigation to build up a huge database in order to have all available materials integrated. As a prospect the Fast Impact Assessment and the Guideline to Achieve a Greener Product should be implemented in the process of development. Philips should think about incorporating biobased materials in their product portfolios and their product roadmaps for the future. Because the production figures of biobased plastics indicate that these sort of ecologically friendly material will be the one for the future.

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Abbreviations

ABS	Acrylonitrile Butadiene Styrene
ASTM	American Society for Testing and Materials
BBP	Butyl Benzyl Phthalate
BFR	Brominated Flame Retardant
BOM	Bill of Material
BPA	Bisphenol A
C2C	Cradle to Cradle
CA	Cellulose Acetate
CAB	Cellulose Acetate Butyrate
CAP	Cellulose Acetate Propionate
CE	European Conformity
CFC	Carbon Footprint Calculation
CH4	Methane
CL	Consumer Lifestyle
CMR	Carcinogenic Mutagenic Reprotoxic
CO2	Carbon Dioxide
DBP	Dibutyl Phthalate
DC	Direct Current
DEHP	Bis (2- ethylhexyl) phthalate
DFU	Directions for Use
EBM	Environmental Benchmarking
EDF	Environmental Defense Fund
EI 99’	EcoIndicator 99’
EPS	Expanded Polystyrene
EQDF	Environmental Quality Function Deployment
FOA	Food and Agriculture Organization
GaBi	Ganzheitliche Bilanzierung, German for life cycle engineering

GDP	Gross Domestic Product
GFA	Green Focal Areas
GHG	Green House Gases
GmBH	Gesellschaft mit beschränkter Haftung, German for company with limited liability
GP	Green Product
GWP100	Global Warming Potential in 100 years
HBCDD	Hexabromocyclododecane
HDI	Human Development Index
HDPE	High-density Polyethylene
HFC	Hydrofluorio Carbons
iBIB	International Business Directory for Innovative Biobased Plastics and Composites
IPCC	Intergovernmental Panel on Climate Change
IPR	Intellectual Property Rights
IPP	Integrated Product Policy
ISO	International Organization for Standardization
LCA	Life Cycle Assessment or Life Cycle Analysis
LDPE	Low-density Polyethylene
MET	Material, Energy and Toxic emissions
mPt	Milli points
N.V.	Naamloze Vennootschap, Dutch for a public limited liability company
N2O	Nitrous Oxide
NGOs	Nongovernmental Organization
NRCA	Natural Resources Defense Council
PA	Polyamid
PBB	Polybrominated Biphenyls
PBDE	Polybrominated Diphenyl Ethers
PBT	Persistent Bioaccumulative Toxic

PBT	Polybutylene Terephthalate
PCB	Printed Circuit Board
PCE	Perchloroethylene
PE	Polyethylene
PET	Polyethylene Terephthalate
PFC	Perfluoro Carbons
PHA	Polyhydroxyalkanotates
PHB	3- Hydroxybutyrate
PLA	Polylactic Acid
POM	Polyoxymethylene
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane
PVC	Polyvinyl Chloride
QFD	Quality Function Deployment
Qty	Quantity
REACH	Registration Evaluation Authorization and Restriction of Chemicals
RoHS	Restriction of Hazardous Substances Directive
RSL	Philips Regulated Substances List
SF6	Sulfur Hexafluoride
SVHC	Substances of Very High Concern
TCE	Trichloroethylene
TDCP/TCEP	Chlorinated Flame Retardant
TSCA	Toxic Substances Control Act
USB	Universal Serial Bus
vPvB	Very Persistent Very Bioaccumulative
WEEE	Waste Electrical and Electronic Equipment Directive
WPC	Wood Plastic Compound
WWF	World Wide Fund for Nature

Appendix

Appendix I: Checklist for Design Strategies over Life Cycle

Checklist of design strategies over the life cycle [3]

Life cycle stage	Strategy	Target
Raw material	**Use alternative materials:** Different materials have a varying impact on the environment in their extraction, recycling, or disposal. The requirement for resources and energy also varies depending on the material selected. Replace those materials of a product that have been identified as particularly resource-consuming (such as virgin aluminium, copper, carbon fiber, etc.) by other materials.	Reduction of environmental impact by using environmentally sound materials, recycled materials, renewable materials, etc.
	Use less of a given type of material: An improvement of the environmental impact can generally be realized by reducing material inputs. Minimize the number of materials that cause additional resource consumption.	Reduction of number of materials by design aiming at optimum strength, integration of functions, etc.
Manufacture	**Use less energy and material:** Different methods of manufacture vary as to their environmental impact. They require different amounts of resources and energy to produce a given product. Environmental damage often results from the application of inadequate production processes. Reduce the amount of energy and material necessary for production. Use alternative types of energy. Avoid or reduce the consumption of auxiliary and process materials in the production process?	Reduction of energy consumption throughout production by means of optimized processes, renewable energy, etc. Reduction of environmental impact caused by consumption of process materials in production process (closed cycles, etc.).
	More efficient use of materials: Optimum use of materials in the production process also helps to reduce costs for the procurement of materials as well as for waste disposal. Reduce waste and/or emissions generated in the production process?	Reduction of waste in production through material efficiency, recycling, etc.
	Avoid joints not allowing easy disassembly: Components for service, maintenance can be gathered. Cost can be also saved for assembly.	Easy disassembly if components should be reused.

Table 0-1: Strategies for improvement[179]

[179] Wimmer et al. (2011), p. 197

Life cycle stage	Strategy	Target
Distribution	**Purchase of external materials/ components:** The environmental quality of a product also depends on the quality of the parts and components purchased from other manufacturers. Procure materials, parts, and components in such a way as to ensure environmentally sound manufacture. Reduce the requirement for transportation in the procurement of external parts.	Procurement of environmentally sound product parts (energy saving, production processes, hazards, etc.).
	Change packaging: As packaging material is useful only for a limited period of time (unless it is returnable) the type and quantity of material used for packaging should be optimized. Especially with products that have to be transported over long distances, the weight of the packaging material, too, has a great influence on the overall consumption of resources. Reduce the weight of the packaging material (often no packaging is required for transportation). Use returnable packaging or renewable or recycled materials for packaging?	Optimization of packaging by taking into account material characteristics, renewability, closed cycles, etc.
Product use	**Realize a high degree of functionality** Reliable and functionally optimized products ensure maximum benefit from the resources used and guarantee customer satisfaction. Improve the functional quality of the product (and its components). Prolong the useful life of the product by means of regular tests of its functionality and operational safety?	Improved functionality by means of upgrading, multi-functionality, etc. (as long as the environmental impact doesn´t exceed limits). Improving maintenance through wear detection, remote control, etc.
	Ensure safe use of the product: With products that are used intensively, operational safety is particularly important. Does the product hold a potential risk to the environment. Take measures that minimize this risk.	Avoiding waste during product use. Avoiding risks.
	Reduce energy and material input at use stage: The more often a product is used, the greater the proportion of resources that are used up and waste and emissions generated at the use stage in relation to the overall environmental impact caused by the product during its life cycle.	Reducing the consumption of energy and process materials during product use. Reducing the amount of waste and emissions generated during the use of the product.

Table 0-2: Strategies for improvement[180]

[180] Wimmer et al. (2011), p. 198

Life cycle stage	Strategy	Target
	Use the product as intensively as possible; make intensive use of resources: Optimum utilization of the product ensures an efficient use of the valuable resources contained in the product. Improve handling, functionality, and thus the overall functional quality of the product (and its components). Products that are easy to handle and that require little maintenance, make for efficient use. Extend the service life by means of regular tests of the functionality and operational safety of the product.	Improved usability of products through adaptability, ergonomics, etc. Improved functionality by means of upgrading, multi-functionality, ... Improving maintenance through wear detection, remote control etc.
	Use the product longer; longer use of resources A long service life of the product also ensures efficient use of the individual parts and components. Ease of repair prevents premature disposal of the product. Prolong the service life of the product also through reuse of components. (A too high energy consumption compared to new products in the market can limit the application.)	Durability through dimensioning, surface design, etc. Improving access to, disassembling, and exchange, etc., of parts.
	Environmentally compatible documentation: Use paper free-instructions or, if necessary, environmentally compatible paper. Inform about environmentally compatible use and take-back or recycling.	Involve consumers.
End-of-life	**Disassembly and Recycling** The more parts and components of the product can be reused and the easier materials can be recycled, the less material has to be disposed of; the input necessary for disposal will be limited and resources contained in the product may be reused or recycled. Design should aim at reusing parts and components as this approach avoids the destruction of the structure of components and thus preserves the value of individual parts. Recycle materials (together with recycler).	Organize product take back and ease of disassembling (fastness, etc.). Organize reuse of parts (access, remanufacturing, etc.), also reuse of qualified as new components in new products. Organize recycling of materials (separation, labeling etc.).

Table 0-3: Strategies for improvement[181]

[181] Wimmer et al. (2011), p. 199

Appendix II: Investigating the Product

The main intention of this substitution was to drive for the biggest improvement potential. In order to identify the parts with the highest influence on environment, the selection was based on a LCA using the EcoIndicator 99' method. When the EcoIndicator 99' values from each part were calculated, the list of all part were ranked in terms of their EcoIndicator 99' values.

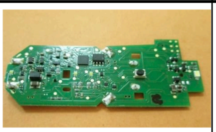
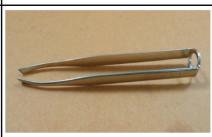
Ranking	Name	Image	Qty	Weight in g for single piece	EI-99 (mPt)	EI-99 in %	Material	Process
1	Adaptor assembly__Cable		1	25,93	183,5	27,39%	TPE-PP ??	Standard
2	Electronic assembly_Motor Assembly_Motor with Gear		1	40,13	106,9	15,96%	Copper	Standard and injection molding
3	Satin Perfect assembly (Small)_Electronic assembly_Motor		1	31,96	87,25	13,02%	Copper	Standard
4	Cutting Element Assembly_Smart Tweaser _End cap		1	1,3	53	7,91%	SST	Machining
5	Adaptor assembly__PCB		1	45,71	24,42	3,65%	Composite	Standard
6	Electronic assembly__PCB		1	5,85	16,41	2,45%	Composite	Standard
7	Adaptor assembly__Adopter Body		1	24,9	14,23	2,12%	PC	Injection molding & Machining
8	Satin Perfect assembly (Small)_Housing assembly_Top Cover		1	13,56	13,56	2,02%	ABS	Injection Molding
9	Cutting Element Assembly_Smart Tweaser _Tweaser		1	8,33	12,92	1,93%	SST	Punching
10	Satin Perfect assembly (Small)_Electronic assembly_Battery		2	22,41	11,36	1,70%	AA, alkaline	Standard

Table 0-4: Top 1-20 of LCA

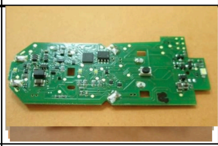
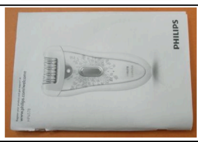
Ranking	Name	Image	Qty	Weight in g for single piece	EI-99 (mPt)	EI-99 in %	Material	Process
11	Satin Perfect assembly (Small)_Housing assembly_Motor Housing		1	8,63	8,63	1,29%	POM	Injection Molding
12	Satin Perfect assembly (Small)_Housing assembly_Battery Cover		1	6,66	6,6	0,99%	ABS	Injection Molding
13	Satin Perfect assembly (Small)_Housing assembly_Bottom Cover		1	6,27	6,27	0,94%	ABS	Injection Molding
14	Cutting Element Assembly_Smart Tweaser _Tweaser Cover Cap		1	5,14	5,81	0,87%	ABS	Injection Molding
15	Packaging__Fancy cover		1	98,16	5,79	0,86%	Paper	Standard
16	Packaging__Product Tray		1	15,06	5,62	0,84%	PS	Expanding
17	Housing assembly__Bottom Cover		1	14,17	5,6	0,84%	ABS	Injection Molding
18	Adaptor assembly__Cover		1	11,53	5,57	0,83%	PC	Injection molding
19	Packaging__Blister cover		1	15,06	5,51	0,82%	PET	Blow Forming
20	Packaging__Instructio n Manual		1	90	5,31	0,79%	Paper	Standard

Table 0-5: Top 11-20 of LCA

After that the most relevant parts were chosen for the further procedure. The DC motors were skipped because there is no possible solution to substitute, nowadays. In addition, the PCBs were out of scope and therefore they were not investigated further. The result of the ranking and the selection are illustrated in Table 0-6.

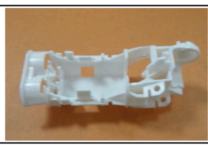
Rank	Name	Image	Qty	Weight in g for single piece	EI-99 (mPt)	EI-99 in %	Material	Process
1	Adaptor assembly__Cable		1	25,93	183,5	27,39%	TPE-PP	Standard
7	Adaptor assembly__Adopter Body		1	24,9	14,23	2,12%	PC	Injection molding & Machining
8	Satin Perfect assembly (Small)_Housing assembly_Top Cover		1	13,56	13,56	2,02%	ABS	Injection Molding
11	Satin Perfect assembly (Small)_Housing assembly_Motor Housing		1	8,63	8,63	1,29%	POM	Injection Molding
12	Satin Perfect assembly (Small)_Housing assembly_Battery Cover		1	6,66	6,6	0,99%	ABS	Injection Molding

Table 0-6: Selected parts for further investigation

The columns in Table 0-6 are quantity (Qty), the weight of the parts, the EcoIndicator value 99' (EI-99), the Ecoindicator 99' percentage is calculated by the EcoIndicator 99' value of the part divided by the EcoIndicator 99' value of the product, the material and the manufacturing process.

The reason for the high environmental impact of the cable is the linear dependency of EcoIndicator 99' and the length. If the cable is cut in half-length the EcoIndicator 99' value will also halve.

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Appendix III: Greenpeace Ranking Criteria in Detail

Criterion					
C1. Precautionary Principle	**C2. Chemicals Management**	**C3. PVC and BFR phase-out and timeline[1]**	**C4. Phase-out of additional substances with timeline(s)**	**C5. PVC-free and BFR-free models (product systems) on the market**	Points to be scored for each
Support for the precautionary principle and public support for RoHS 2.0 in line with the public statement (in box below), and *proactive* support for RoHS 2.0[2] to introduce end-of-life focused methodology and, consequently, ban on organo-chlorine and organobromine substances	Lists restricted/ banned substances and communications along supply chain, plus a list of substances in consideration for future restriction and criteria used for identifying 'future substances' for elimination	Commitment to complete PVC and BFR phase-out and reasonable timeline for ALL applications	3 named substances[3] and reasonable timelines for all new models[4]	Yes, both PVC-free and BFR-free (double points)	3

Table 0-7: Toxic chemicals criteria in depth[182]

Criterion					
W1. Support for Individual Producers Responsibility[5]	**W2. Provides effective[6] voluntary take-back where no EPR laws**	**W3. Provides info for individual customers on take-back in all countries where sales of product**	**W4. Reports on amount of e-waste recycled[7]**	**W5. Use of recycled plastic content across all products and timelines for increasing content**	Points to be scored for each
Public and explicit demand and support for IPR from all actors[8], such that the end-of-life management systems[9] support own-brand differentiation[10] and internalisation of real own-brand end-of-life costs, including ensuring high recycling standards	Free, easy and GLOBAL take-back for ALL products in all countries where products are sold	Clear info on what individual customers can do with e-waste accessible to customers in every country where products are sold	Reports on the global[11] amount recycled as percentage of past sales by product type and achieves over 25% recycling rate for at least one specified product group[12]	At least 15% of all plastics sourced is recycled plastic[13], AND timeline for increasing to 25%	3

Table 0-8: E-waste criteria in depth[183]

[182] Greenpeace (2010), p. 2

		Criterion			
E1. Support for global mandatory reduction of GHG emissions	**E2. Disclosure of carbon footprint (GHG emissions) of company's own operations and two stages of the product supply chain**	**E3. Commitment to reduce GHG emissions from a company's own operations with timelines[14]**	**E4. Amount of renewable energy[15] used as proportion of total electricity use in own operations**	**E5. Energy efficiency of new models of specified products[16]**	Points to be scored for each
Supports global mandatory cuts of at least 50% by 2050 (from 1990 levels); cuts by industrialised countries of at least 30% as a group by 2020[17] and for greenhouse gas emissions to peak by 2015	Disclosure of ISO 14064-certified[18] GHG emissions from company's own operations and those of at least two supply chain stages[19]	Commitment to reduce GHG emissions from own operations by at least 20% by 2012	Proportion of renewable energy in total electricity use of company's own operations above 25%	All new models of specified products meet the latest Energy Star standard and 30% exceed the Energy Star standard (by 50% or more in sleep and standby/no-load modes, where applicable) (double points)	**3**

Table 0-9: Energy criteria in depth[184]

Appendix IV: All Harmful Chemical of NDRC

The following chemicals are stated as harmful according to NDRC. [185]

- 1,4-Dioxane
- Arsenic
- Asbestos
- Atrazine
- Bisphenol A (BPA)
- Carbaryl
- Chlorpyrifos
- Diesel
- Dioxins
- Endosulfan
- Fluoride
- Formaldehyde

[183] Greenpeace (2010), p. 7
[184] Greenpeace (2010), p. 10
[185] NRDC Chemicals

- Hexavalent Chromium
- Lead
- Lindane
- Mercury
- Methylene chloride (dichloromethane)
- n-hexane
- Nanomaterials
- Ozone
- Parabens
- Perchlorate
- Perchloroethylene (Tetrachloroethylene, PERC, PCE)
- Phthalates
- Propoxur (Flea and Tick Pesticide)
- Pyrethrins
- Pyrethroids
- Styrene
- Sulfur Dioxide
- TDCP/TCEP (Chlorinated Flame Retardants)
- Tetrachlorvinphos (Flea and Tick Pesticide)
- Trichloroethylene (TCE)
- Triclosan
- Triclocarban (Antibacterials)

Appendix V: Material Request

Dear Mr. XY!

We are looking for biobased plastic materials for Philips handheld appliances for personal care (e.g. shavers).
We would need material proposals of biobased materials on following types of parts:

- Part 1: housing part: highly visual part, high gloss surface, good impact resistance and good environmental resistance, all colors possible, biobased ratio >40%
- Part 2 like part 1, but with matt surface instead of high gloss surface, biobased ratio >40%
- Part 3: technical inner part: no visual and environmental requirements, no colors, with high biobased ratio >80%
- Part 4: housing part, highly visual part with high biobased ratio >80%
- Part 5: highly visual, clear transparent part, transmission grade >87%, biobased ratio >40%

Some general information (more information and requirements, see attachment):

- General material lifetime requirements: 5 years without major decrease of main material properties and visual appearance
- Material demand >25-50 tons per year
- Biobased material= organic material in which carbon is derived from a renewable resource via biological processes

If you can offer suitable materials and you are interested, we would kindly ask you to deliver us the following information, if possible within one week:

- Material proposals for parts 1-5
- Material cost in €/ kg (1 ton/ 5 tons)
- Comments, what requirements are not fulfilled with proposed materials
- Material datasheet, Material safety datasheet, additional information

Figure 0-1: Request for biobased material

Appendix VI: LCA Study of PLA

In addition to studying the properties of biobased materials also the eco-profile was considered. Erwin T.H. Vink et al[186] did a LCA benchmarking on current PLA (Ingeo from NatureWorks LLC) versus fossilbased material in terms of ecological aspects. The outcome of their study was that PLAs have a lower impact on environment. The results are shown in the following Figure 0-2. The values represent the GHG emissions and are calculated on CO2 equivalent base.

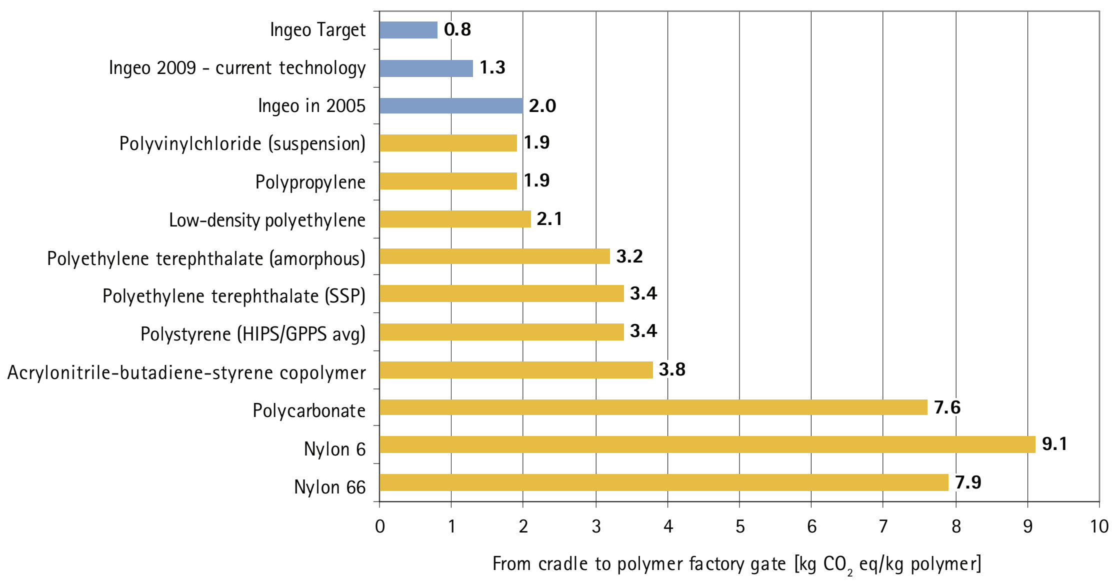

Figure 0-2: Benchmarking for greenhouse gas emissions[187]

[186] Cf. Vink et al. (2010), pp. 212
[187] Vink (2010), p. 223

Appendix VII: All Lists of Assessed Materials

The following tables shows the steps in between the selection process.

Company	Product Name	Material	Biobased Content	Not in conflict with food supply	Quality requirements	Price	Year Production	Young's Modulus	Charpy impact notched 23C	Processability	Transmission grade	Visual quality	Response	Sum	most relevant (yellow)
BASF	Terluran GP-22	ABS	1	5	5	5	5	3	5	5	1	5	5	45	24
FKUR	BioGrade C 9550/ C7500	Cellulose Acetate	3	5	5	3	4	4	3	3	5	5	5	45	23
DSM	Ecopaxx Q-X70208	PA 4.10 with GF	2	3	5	3	4	5	5	4	1	3	5	40	23
Hipro	Hiprolon 200 FN/NN/VN	PA 10.10	5	3	4	2	3	2	4	4	4	4	4	39	21
Tecnaro	Abroblend V1/V2/V3/V4/V5	Wood compound	3	5	4	5	3	4	5	4	1	3	1	38	24
Unitika Terramac	TE-2000	PLA	5	1	4	4	4	4	1	4	5	5	1	38	23
NatureWorksLLC	Ingeo Biopolymer 3052D	PLA	5	1	4	4	5	3	1	3	5	5	2	38	22
NatureWorksLLC	Ingeo Biopolymer 3251X	PLA	5	1	5	3	5	3	1	3	5	5	2	38	22
NatureWorksLLC	Ingeo Biopolymer 3001D	PLA	5	1	3	4	5	3	1	4	5	5	2	38	21
DSM	Ecopaxx Q150D	PA 4.10	4	3	4	2	4	4	2	4	1	5	5	38	21
FKUR	BioFlex F 6510/ S5630/ S6540	PLA	4	1	4	4	4	3	3	3	1	5	5	37	23
Arkema	Rilsan® Clear G830 Rnew	PA	2	3	5	2	4	2	4	4	5	5	1	37	20
FKUR	Fibrolon P 7550/ P8540	PP + Wood fibres	2	5	5	5	3	3	2	4	1	2	5	37	19
Toray	V751X52/CA05-011/CA05-003/CA05-076/V551-X52	PLA	1	1	5	4	5	3	4	4	1	5	3	36	22
NatureWorksLLC	Ingeo Biopolymer 3801X	PLA	5	1	5	3	5	2	5	3	1	3	2	35	23
Hipro	Hiprolon 70 FN/NN/VN	PA 6.10	3	3	4	3	3	3	3	4	1	4	4	35	20
FKUR	Fibrolon P 8530	PLA + Wood fibres	4	3	4	4	3	4	2	3	1	2	5	35	20
Green Gran	N 026J/ F023J	PP+ natural fiber	2	5	4	4	2	5	2	4	1	2	4	35	19
Toray	V511-X01/CA05-069/CA11-013/CA11-004	PLA	3	1	3	4	4	3	4	4	1	4	3	34	21
Toray	CA15-003/CA15-004	PLA	3	1	4	4	5	3	3	4	1	3	3	34	20
Toray	V911X51	PLA	1	1	5	3	4	4	1	3	5	4	3	34	18
Biomer	P209/ P226	PHB HV	5	4	4	2	3	2	2	3	1	3	4	33	18
Biocycle	189C-1/ 1000/ 189 D-1	PHB HV	5	4	4	2	3	3	3	3	1	3	1	32	20
Mirel	P1003/F1005	PHA	5	4	4	2	4	4	1	3	1	3	1	32	19
Tecnaro	Abroform F 45 natur/ ZE 50 natur 7/ L, V3 natur	Wood compound	3	5	3	5	3	5	1	4	1	1	1	32	18
Unitika Terramac	TE-7000/7307/7300	PLA	5	1	4	3	4	5	1	3	1	3	1	31	21
Unitika Terramac	TE-8210/8300	PLA	5	1	4	2	4	5	2	3	1	3	1	31	21
Toray	CA29-001	PLA	4	1	3	3	4	5	2	3	1	2	3	31	19
DuPont	Zytel RS LC3030/60/90 NC010	PA 6.10	3	3	4	3	3	3	2	3	1	3	3	31	18
Mirel	P1004/F1006	PHA	5	4	4	2	4	2	2	3	1	3	1	31	18
Ecolgreen	EGP 100-I	PLA	5	1	3	2	3	4	2	3	1	3	3	30	19
PolyOne	reSound RS 1200-001/1200-002	PLA/PHB	2	2	4	2	3	2	5	2	1	5	1	29	20
Ecolgreen	EGP 100-I-HR	PLA/PBS	3	1	4	2	3	4	2	3	1	3	3	29	18
Unitika Terramac	TE-1030/1070	PLA	5	1	4	3	4	2	1	3	1	3	1	28	18
DuPont	Sorona 3301 BK001	Corn starch	1	1	4	2	3	5	2	3	1	3	3	28	17

Table 0-10: List of assessed materials

Company	Product Name	Material	Biobased Content	Not in conflict with food supply	Quality requirements	Price	Year Production	Young's Modulus	Charpy impact notched 23C	Processability	Transmission grade	Visual quality	response	sum of all criteria	sum of most relevant criteria
FKUR	BioGrade C 9550/ C7500	Cellulose Acetate	3	5	5	3	4	4	3	3	5	5	5	45	23
FKUR	BioFlex F 6510/ S5630/ S6540	PLA	4	1	4	4	4	3	3	3	1	5	5	37	23
NatureWorksLLC	Ingeo Biopolymer 3801X	PLA	5	1	5	3	5	2	5	3	1	3	2	35	23
Hipro	Hiprolon 200 FN/NN/VN	PA 10.10	5	3	4	2	3	2	4	4	4	4	4	39	21
Toray	V511-X01/CA05-069/CA11-013	PLA	3	1	3	4	4	3	4	4	1	4	3	34	21
Biocycle	189C-1/ 1000/ 189 D-1	PHB HV	5	4	4	2	3	3	3	3	1	3	1	32	20

Table 0-11: Suitable material for Housing

Company	Product Name	Material	Biobased Content	Not in conflict with food supply	Quality requirements	Price	Year Production	Young's Modulus	Charpy impact notched 23C	Processability	Transmission grade	Visual quality	response	Sum of all criteria	Sum of the most relevant criteria
Tecnaro	Abroblend V1/V2/V3/V4/V5	Wood compound	3	5	4	5	3	4	5	4	1	3	1	43	24
FKUR	BioGrade C 9550/ C7500	Cellulose Acetate	3	5	5	3	4	4	3	3	5	5	5	50	23
FKUR	BioFlex F 6510/ S5630/ S6540	PLA	4	1	4	4	4	3	3	3	1	5	5	42	23
Toray	V511-X01/CA05-069/CA11-013/CA1	PLA	3	1	3	4	4	3	4	4	1	4	3	39	21
Biocycle	189C-1/ 1000/ 189 D-1	PHB HV	5	4	4	2	3	3	3	3	1	3	1	37	20
FKUR	Fibrolon P 7550/ P8540	PP + Wood fibres	2	5	5	5	3	3	2	4	1	2	5	42	19

Table 0-12: Suitable material for innerparts

Company	Product Name	Material	Biobased Content	Not in conflict with food supply	Quality requirements	Price	Year Production	Young's Modulus	Charpy impact notched 23C	Processability	Transmission grade	Visual quality	response	Sum of all criteria	Sum of the most relevant criteria
FKUR	BioGrade C 9550/ C7500	Cellulose Acetate	3	5	5	3	4	4	3	3	5	5	5	50	23
NatureWorksLLC	Ingeo Biopolymer 3052D	PLA	5	1	4	4	5	3	1	3	5	5	2	43	22
Arkema	Rilsan® Clear G830 Rnew	PA	2	3	5	2	4	2	4	4	5	5	1	42	20

Table 0-13: Suitable material for transparent parts