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ECODESIGN

Best Practice of ISO/TR 14062

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PREFACE

The increasing demand to preserve the environment, conserve resources, and form a sustainable society led to the publication of two types of ISO 14000 standards: management oriented and product oriented. The ISO 14000 product oriented standards includes Environmental Labels and Declarations, Life Cycle Assessment, and Design for Environment. These standards are intended to assess and report the environmental performance of products and services, and provide guidance on improving environmental performance within a product/service. These standards may serve as norms for environmental consideration in international trade, as a result implying that these standards have the potential to become technical facilitators as well as barriers to trade.

The ISO 14000 product oriented standards are not easy to comprehend and require expert knowledge to exercise them appropriately. As most APEC developing economies do not have expertise on these standards there is a strong need to produce best practice books that enhance the level of understanding and use of these standards. This is the third of three books on the product-oriented ISO 14000 series standards to be produced as part of the APEC CTI/TILF project.

A new paradigm termed sustainable consumption and production has been accepted as the ultimate goal to achieve in today's society. It is a well-known fact that mass consumption as well as mass production of industrial products cause major adverse impacts on the environment, such as climate change and ozone layer depletion. Conventional end-of-pipe environmental regulation focuses only on the emissions from the manufacturing processes of a product. Often times, however, adverse impacts on the environment occur from the other life cycle stages such as use, disposal, distribution, and raw material acquisition. Without reducing environmental impacts from the entire life cycle of a product, one cannot mitigate the environmental problems that accrue from the production and consumption of the product.

Many corporations recognized the importance of the environmental impacts of their products and began to incorporate positive environmental aspects into their product design and development processes. This requires identification of key environmental issues related to the product throughout its entire life cycle. These key issues include problematic activities, processes, and materials associated with the product including use of raw materials, manufacturing, distribution, use, and end of life, or entire life cycle. Since a product cannot exist without materials, components, transportation, disposal, and energy, identification of key environmental issues of a product in its entire life cycle is a complicated process. In addition, demands for environmentally friendly products from the stakeholders such as society, governments and competitors are important factors to be incorporated in developing and designing products.

Ecodesign is a systematic process that incorporates significant environmental aspects of a product as well as stakeholder requirements into product design and development. ISO/TR 14062 is an international standard that provides guidance in implementing ecodesign. The terms and definitions taken from ISO/TR 14062 are reproduced with the permission of the International Organization for Standardization, ISO. These standards can be obtained from any ISO member and from the Web site of the ISO Central Secretariat at the following address: www.iso.org. Copyright remains with the ISO.

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1. INTRODUCTION

1.1 Background

Environmental problems we face today are not limited to one region or country. They are worldwide problems affecting all human beings. In the attempt to deal with environmental problems, the UN Conference on Environment and Development (UNCED) was held in Rio in June 1992. In this meeting, also termed the 1st Earth Summit Meeting, the UNCED adopted the concept of "Environmentally Sound and Sustainable Development" (ESSD) as a new paradigm for the solution to worldwide environmental problems. One decade later, the 2nd Earth Summit (World Summit on Sustainable Development; WSSD) was held in Johannesburg, South Africa. In this meeting, the WSSD concluded that sustainable consumption and production are the only means to achieve sustainable development in the world (UNEP 2002).

The concept of sustainable development aims at attaining and balancing both economic development and environmental preservation. In line with this concept, environmental policy has shifted from the end-of-pipe approach to the pollution prevention approach. Environmental regulation has since moved from direct and mandatory mandates by authorities to indirect and voluntary compliance by the manufacturers and consumers.

Industrial products are a major source of today's environmental problems. Sustainable development entails that manufacturers of industrial products take into account the environmental impacts throughout the entire life cycle of a product, not just focusing on environmental pollutants during the manufacturing of the product. This holistic approach is key to the minimization of resource consumption, as well as the reduction of environmental pollutants. For consumers, consumption habits are geared towards sustainable consumption, where the consumer purchases environmentally friendly products or ecoproducts. Ecoproducts use less resources, generates less waste, and its production consequences less pollution.

As with the enhanced understanding of the consumers on the sustainable consumption, there is increased cooperation among stakeholders including governments, consumers, and non-governmental environmental organizations. In response to this increased cooperation, there are a growing number of legal regulations on the environmental requirements of products in various parts of the world. In addition, international agreements on the minimization of environmental problems such as the Kyoto protocol on global warming are on the rise.

The EU is the most active region in the world, enforcing the holistic view of a product and adopting the Polluter Pays Principle based on the extended producer responsibility concept. The Integrated Product Policy (IPP) (CEC 2001) is a prime example of the EU's policy on environmental regulations on products. The EU has passed environmental regulatory directives in the field of automotives and electrical and electronic equipment (EEE) that include the End of Life Vehicle (ELV) directive (CEC 2000), the Waste Electrical and Electronic Equipment directive (WEEE) (CEC 2003a), the Restrictions of the use of certain Hazardous Substances in EEE directive (RoHS) (CEC 2003b), among others. In addition, the EU is in the process of finalizing a framework directive for setting eco-design requirements for energy-using products (EuP) (CEC 2003c).

One of the major differences between the WEEE and RoHS directives, and the proposed EUP directive is that the former was based on the so-called *old approach*. The *old approach* suggests that all the implementation measures of the requirements are already delineated in the directive leaving less room for misinterpretation. The *new approach*, however, does not stipulate details of implementation, rather implementation measures are later be prepared by the appropriate EU ministries that use the directive as a guide rather than a reference. Hence, the term "framework directive" that is often coined to describe the proposed EuP directive.

For instance, one of the requirements of the proposed EuP directive, is that all products entering the EU market must demonstrate that the product was designed in accordance with the ecodesign principle. All in all, increasing environmental regulations pose a significant amount of pressure on the industries for the development of environmentally conscious products, or ecoproducts. As a result, the industries have no other option but to develop ecoproducts, which will lead to technological innovation of products and services.

The objectives of this ecodesign book are two-fold. First, to disseminate information about product-related environmental regulations focused on ecodesign and secondly, to provide guidance of the implementation measures of ecodesign to the APEC member economies. Target audiences of this book include product designers and developers, standard developers, and trade experts, among others.

1.2 What is ecodesign

In the past, products have been designed and developed without considering its adverse impacts on the environment. Typical factors considered in product design included function, quality, cost, ergonomics and safety. However, no consideration was given specifically to the environmental aspects of a product throughout its entire life cycle. Conventional end-of-pipe regulation focused only on the emissions from the manufacturing processes of a product. Often times, adverse impacts on the environment occurred from other life cycle stages such as use, end-of-life, distribution, and raw material acquisition. Without addressing the environmental impacts from the entire life cycle of a product, one cannot resolve all the environmental problems accruing from both the production and consumption of the product.

Many corporations recognized the importance of the environmental impacts of their products and began to incorporate significant environmental aspects into their product design and development processes. This required the identification of key environmental issues related to the product throughout its entire life cycle. The key issues included problematic activities, processes, and materials associated with the product from raw materials acquisition, manufacturing, distribution, use, and disposal, in other words, the entire life cycle.

Product design and development relating to improved environmental performance has many expressions including design for environment, ecological design, environmental design, environmentally conscious design, environmentally responsible design, socially responsible design, sustainable product design, sustainable product development, green design and life cycle design. In this book, we will use ecodesign as a term of choice.

There are several different ways to define ecodesign. ISO/TR 14062 defined ecodesign as an activity that integrates environmental aspects into product design and development. The integrated activities lead to continual improvement of the environmental performance of the product through technological innovation (ISO 2002). Fiksel (1996) defined ecodesign as a process that develops a product that meets cost, performance, quality, as well as environmental attributes of a product by integrating environmental aspects into product design engineering process. Karna (1998) defined ecodesign as a process that reduces the environmental load of a product in its entire life cycle by considering environmental aspects of a product in the entire product development process. Keoleian and Menerey (1993) stated that a systematic approach is required for the design of a product system that is ecologically and economically sustainable. They further stressed that the physical life cycle of a product must be linked to the product development cycle. There are other literatures defining ecodesign (Graedel and Allenby 1995, Sherwin and Evans 2000).

Based on the existing definitions of ecodesign, we define ecodesign in this book as an activity that identifies the environmental aspects of a product and then integrates them into product design process in the early stage of a product development process. Other factors including function, cost, performance, quality, and legal and technical aspects must be considered during the ecodesign process.

As shown in Figure 1.1, environmental impact of a product is determined early in the product design and development process where material composition and product performance are fixed. Accordingly key environmental issues must be identified early in the design process and be reflected into the product design.

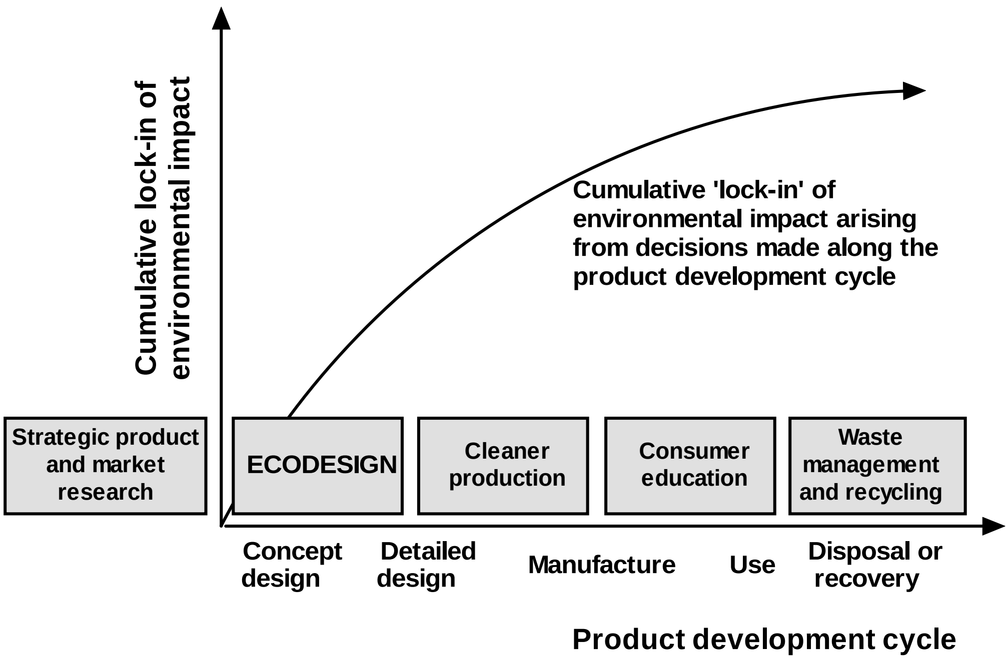

Figure 1.1 Conceptual representation of environmental 'lock-in' over a product's development stage (Lewis and Gertsakis 2001)

There are four R approaches to pollution prevention caused by products: repair, refine, redesign and rethink. Repair is an approach that solves existing problems of products via end-of-pipe treatment. Refine is an approach that increases eco-efficiency of existing products. Redesign is an approach that redesigns products using new technologies and materials. Rethink is an approach that develops new products based on new paradigm changes of a society (Charter and Tischner 2001). Refine and rethink have relevance to ecodesign because both approaches involve product design with improved environmental performance.

A pyramid like structure as shown in Figure 1.2, though similar to the four R approaches, can better describe the role of ecodesign for the abatement of the environmental problems caused by products.

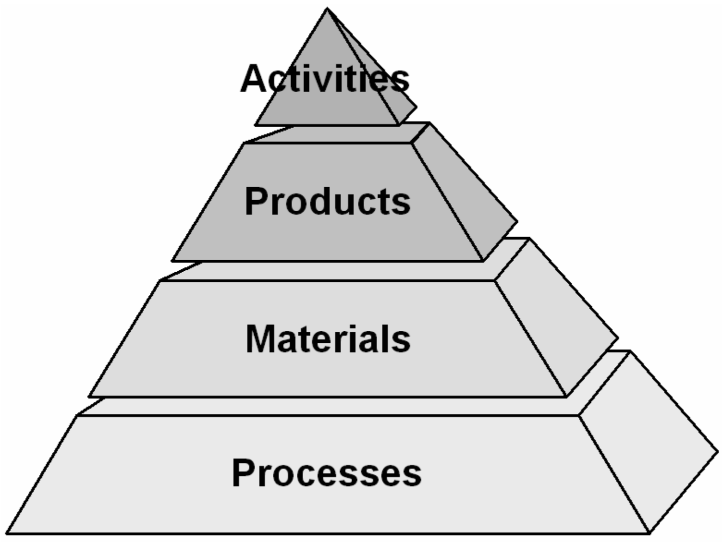

Figure 1.2 Priority of precautionary prevention options

Processes, at the bottom of the pyramid indicates the adoption of cleaner production processes where products are manufactured with improved environmental performance during its manufacturing. This is the easiest, but least effective option in abating environmental problems caused by products. The second from the bottom, Materials, indicates the use of eco friendly materials for products. The third option, Products, is an advanced option over the Processes and Materials options by addressing environmental problems of a product from its inception by designing a product eco friendly. The highest option, Activities, involves the change in existing production and consumption patterns of a society or social paradigm change in production and consumption. This option is equivalent to the rethink option in Figure 1.1, and can be the ultimate goal to striving for the attainment of sustainable development.

There are four types of ecodesign stages in accordance with the degree of achieving eco-efficiency (Figure 1.3) The four types are similar to the pyramid structure as shown in Figure 1.2. The first type is to improve environmental performance of a product partially. The second is to redesign existing products. The third is to develop new products to fulfill function based on new concepts. The fourth is to design a product by finding innovative solution of a product based on product system.

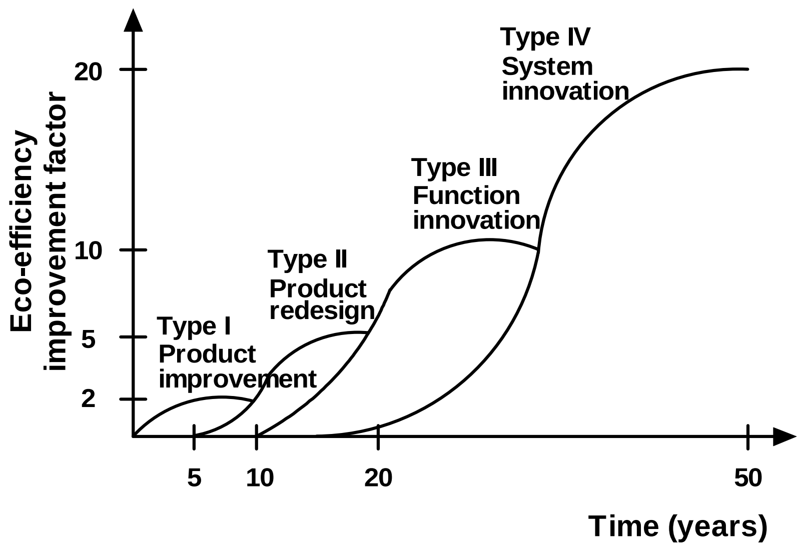

Figure 1.3 Four types of ecodesign (Rathenau Institute 1996)

1.3 Ecodesign methods

Wimmer et al (2004) proposed an ecodesign approach, which we considered one of the most practical and doable ecodesign methods in the field. The ecodesign approach proposed by Wimmer et al was based on an assumption that ecodesign was aimed at improving the environmental performance of an existing product.

Often times, people responsible for ecodesign do not understand the product design and development process. Inevitably this lack of understanding leads to miscommunication or communication gaps between ecodesign team and product designers. Consequently the net result is a poor reflection of the ecodesign concept in product design and development.

The systematic approach in implementing ecodesign (Figure 1.4) overcame the shortcomings of the preexisting practices of ecodesign. As shown in Figure 1.4, ecodesign is considered one of the several steps in developing a product aimed at improving the environmental performance of the product. This indicates that ecodesign cannot exist alone. It is only one part of the product design and development process. Particulars of each of the step in Figure 1.4 follow.

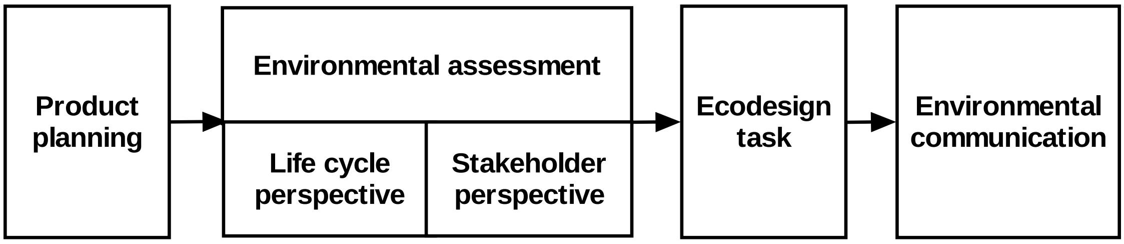

Figure 1.4 Ecodesign approach

The product planning stage includes; identifying product components, parts, materials, collecting life cycle stage information of the product, identifying market characteristics, selecting a product for development, and finally setting up a project team and project target. Allocating budget and personnel including the characteristics of cross-functional teams are also determined in this stage.

The outcome from this task is the product composition, product system, and life cycle stage data. In addition, technical parameters of the product relevant to the significant environmental aspects, i.e., environmental parameters, are also identified.

The environmental aspects of a product are assessed from two different perspectives: the life cycle perspective and the stakeholder perspective. The former is to assess the environmental aspects of a product system based on the environmental impact caused by the product system. The latter is to assess the environmental aspects of a product based on the stakeholders' viewpoint such as legal requirements, market demands, and competitor's products. Commonly used tools for the former include life cycle thinking and/or Life Cycle Assessment (LCA). For the latter, the environmental quality function deployment and the environmental benchmarking are common tools in use.

Instead of full LCA, simplified or screening LCA is often considered a practical tool for the environmental assessment of a product for ecodesign. Simplification can be made either by reducing the effort for data collection or focusing only on particular types of environmental impacts or parameters. Through the use of similar data or databases, by omitting certain life cycle stages, and by the exclusion of particular inventory parameters simplification can be achieved. Performing LCA on CO_2 is an example of the latter approach.

The outcome from the environmental assessment task is a set of significant environmental parameters of a product on the environment. Ecodesign task commences with these parameters. Wimmer et al (2004) developed a 12-step approach in implementing ecodesign based on the ecodesign approach shown in Figure 1.4. The 12-step approach is summarized in Table 1.1.

Table 1.1 Twelve steps for implementing ECODESIGN in practice (Wimmer et al 2004)

Step	Leading questions	Tasks
1	What product is to be redesigned?	Describing the reference product with environmental parameters.
2	What are the stakeholder requirements? What is expected from the product?	Performing Environmental Quality Function Deployment.
3	What are the strengths and weaknesses compared with the competitor's products?	Environmental Benchmarking with the competitor's products.
4	What are the significant environmental aspects of the reference product throughout its entire life cycle?	Applying the ECODESIGN PILOT's Assistant or performing Life Cycle Assessment and interpretation of results.
5	How to combine stakeholders' requirements and significant environmental aspects into improvement strategies?	Deriving common ECODESIGN improvement strategies.
6	Which ECODESIGN guidelines should be implemented in the product?	Applying ECODESIGN PILOT's checklists to determine redesign tasks.
7	What are the environmental product specifications to start with?	Starting product improvement.
8	How to modify the functional structure of the product?	Adding new functions to and/or modifying functions of the reference product.
9	How to generate new ideas for the functions of the product?	Performing creativity session and/or searching for patents.
10	How to generate and select the best product concept variants?	Assembling ideas corresponding to each function of the redesigned product concepts and evaluating them against criteria.
11	How does the improved product look like?	Continuing embodiment design and layout, prototyping and testing.
12	How to communicate the environmental improvements of the product to the market?	Performing Environmental Product Declaration or self-declared environmental claims.

Below is a step-by-step procedure to implement ecodesign tasks identified in Table 1.1 with its relevant tools identified in brackets (Wimmer et al 2004).

- Link the significant environmental parameters to relevant environmental strategies. (Any set of environmental strategies and guides)
- Identify relevant implementation measures for the improvement of the environmental parameters belonging to a certain environmental strategy. (Any checklist that allows evaluating implementation measures)
- Develop redesign tasks for the chosen implementation measures.
- Develop product specifications, consisting of fixed and wish specifications.
- Identify functions of the reference product and then add new functions and/or modify existing functions based on the product specification. (Function analysis)
- Generate ideas to realize the function. (TRIZ, brain-writing, brainstorming, patent search, etc)
- Generate variants by assembling a specific product idea corresponding to each function of the newly improved product.
- Develop a product concept by selecting variants. Variants are evaluated against economic, technical, social and environmental criteria.
- Continuing detailed embodiment design, layout, testing, prototype, production, and finally market launch.

Upon the completion of the ecodesign tasks an environmentally improved product or eco-product is developed. The next task is to communicate the environmental aspects of the eco-product to the market with the hope of increasing market share or at the very least to enhance the image of the product and the company.

1.4 ISO standard on ecodesign (ISO/TR 14062)

In 2002, ISO TC 207 issued an ecodesign standard. This standard addresses key factors to consider in ecodesign, and a generic ecodesign approach applicable to all types of products and even services. Below is a brief synopsis of the standard. The synopsis is based on an article that appeared in the ISO Bulletin (ISO, September 2002: Environmental Management: Integrating environmental aspects into product design and development) and was authored by the main author of this book.

All products including services have some impact on the environment, which may occur at any or all stages of the product's life cycle - raw material acquisition, manufacturing, distribution, use, and end of life. These impacts may differ in magnitude, as well as temporal and geographical boundaries. Nowadays, it is a common understanding that products are the major cause of today's environmental pollution as well as depletion of resources.

The interest of various stakeholders in the environmental aspects and impacts of products is increasing. This interest is reflected in discussions among business, consumers, governments and non-governmental organizations concerning sustainable development, design for the environment, trade measures, and government or sector-based voluntary initiatives. This interest is also reflected in the economics of various market segments that are recognizing and taking advantage of these new approaches to product design. These new approaches may result in improved resource and process efficiencies, potential product differentiation, reduction in regulatory burden and potential liability, and costs savings.

More organizations are coming to realize that there are substantial benefits in integrating environmental aspects into product design and development. Some of these benefits may include: lower costs, stimulation of innovation, new business opportunities, and improved product quality.

Integration of environmental aspects into product design

ISO/TR 14062, *Environmental management – Integrating environmental aspects into product design and development*, describes concepts and current practices relating to the integration of environmental aspects into product design and development. The technical report is intended for use by all those involved in the design and development of products, regardless of organization type, size, location and complexity, and for all types of products whether new or modified. It is written for those directly involved in the process of product design and development and for those responsible for the policy/decision-making process. This technical report is not intended for use as a specification for certification and registration purposes; however, it can be used in developing sector-specific documents.

Taking the holistic approach

One of the most prominent features of ISO/TR 14062 is the holistic approach in integrating environmental aspects of products to the existing product design and development processes. Considering not only product issues, but also strategic as well as management issues when integrating environmental aspects is the key to the success of the integration process. This technical report adopts a holistic approach by specifically addressing issues relating to strategic, management and product considerations.

- **Strategic considerations**

Strategic considerations involve the consideration of organizational, product, and communication issues within the context of the organization's existing policies, strategies and structure. Examples of organizational issues include competitors' activities, customer needs, etc. Examples of product-related issues include early integration, life cycle thinking, functionality, etc. Examples of communication issues include internal and external communications.

- **Management considerations**

Management considerations involve the consideration of the management role, proactive approach, existing management system support, multidisciplinary approach, and supply chain management. Some brief points of each consideration follow:

- Management roles include the initiation of the integration process.
- A proactive approach seeks to prevent adverse environmental impacts before they arise.
- In general, the product design and development process is usually part of an existing management system, such as ISO 9001, through which the environmental aspects and product-related activities could be incorporated.
- Multidisciplinary approach involves relevant disciplines and organizational functions such as design, marketing, environment, etc.
- Supply chain management deals with interactions with suppliers, carriers, customers, retailers, and end-of-life actors.

Product considerations

Product considerations involve the consideration of the product-related environmental aspects and impacts, basic issues and strategic environmental objectives.

Product-related environmental aspects and impacts

Products may have a range of environmental aspects (e.g. emissions generated) that result in environmental impacts (e.g. air pollution). The environmental impacts are largely determined by the material and energy inputs and outputs generated at all stages of a product's life cycle.

Basic issues

Early integration, product life cycle, functionality, multi-criteria concepts, and trade-offs are common basic issues for the integration process. Early integration literally means integration of environmental aspects as early as possible in the product design and development process. The product life cycle approach is used to identify the relevant environmental aspects and impacts during the entire product life cycle. Integrating environmental aspects within the functionality of a product (how well the product suits the purpose for which it is intended in terms of usability, lifespan, appearance, etc.) may lead to a solution that has a reduced environmental impact when compared with traditional solutions where design implications are based on only the product itself. Multi-criteria concepts such as a reduction in product weight or volume may reduce the environmental impacts of the product. For example, a reduction in product weight or volume may be the result of optimizing material use, thereby reducing impacts associated with resource depletion. It could also decrease shipping weight or volume, thereby reducing emissions associated with transport. Trade-offs are associated with most design decisions. There are three types of trade-offs associated with design decisions that include, trade-offs between different environmental aspects, environmental benefit trade-offs, economic benefit trade-offs social benefits trade-offs, and environmental, technical and/or quality aspects trade-offs.

Strategic environmental objectives

There are two strategic environmental objectives that include i) the conservation of resources, recycling and energy recovery, and ii) the prevention of pollution, waste and other impacts. The first objective is to optimize the use of resources required for the product (material and energy) without having an adverse effect on its performance, durability, etc. The second objective is to maximize environmental improvements by using measures that prevent pollution, waste or other impacts. Such approaches deal with problems at their source, considerably reducing the causes of environmental impact and the costs associated with end-of-life treatment.

Possible design approaches

An organization may decide upon a combination of design approaches to meet the strategic environmental objectives. Examples of possible design approaches include, the improvement of materials and energy efficiency, and the design for durability, etc. These design approaches are instrumental in generating design options that can be checked against the feasibility and potential benefits for stakeholders.

Product design and development model

A generic model of product design and development in ISO/TR 14062 consists of six stages: planning, conceptual design, detailed design, testing/prototype, market launch, and product review. The *Planning stage* encompasses planning and formulation of product requirements. The *Conceptual design stage* realizes the product requirements. *The Detailed design stage* is additional actions to meet the product design specifications prior to production. The *Testing/Prototype stage* is to check the detailed design against environmental targets and other specifications. The environmental performance of the product such as life cycle assessment results can also be assessed at this stage. The *Market launch stage* is the deliverance the product to the market and the communication of information about the product's features and benefits to the customers. The *Product review* aims to find whether the expectations of the organization, customers etc. have been met. Feedback and criticism from customers and other stakeholders is an important information source for the organization to improve its current or future products.

2. ENVIRONMENTAL ASSESSMENT TOOLS

Environmental aspects of a product must be assessed from two different perspectives. First, are the significant environmental issues inherent to a product throughout its entire life cycle. Second, are the stakeholder requirements of the product (Wimmer et al 2004). Significant environmental issues that are inherent of a product are key processes, and the materials and activities that pose significant impacts on the environment. For instance, emission of CO_2 in the manufacturing process of a product can be a significant environmental issue of a product. On the other hand, the stakeholder requirements include such factors as the product related environmental regulations and/or market pressures regarding environmental issues. For instance, where the WEEE and RoHS regulations in the EU are typical examples of product related environmental regulation, superior environmental performance of the competitor's products is an example of market pressure.

Commonly used tools for the identification of environmental issues of a product include LCA, simplified LCA, and Material, Energy, and Toxic emissions (MET) points. However, in assessing stakeholder requirements, environmental benchmarking, and environmental quality function deployment (EQFD) are commonly used tools. These tools may be classified as quantitative and/or qualitative depending on the nature in which the information is generated by the tools. The assessment of environmental issues may be considered quantitative, while the assessment of stakeholder requirements may be qualitative.

In general, quantitative information provides numeric values based on fairly objective methods as such reliability of the information can be relatively high. In turn, the analysis of the quantitative data requires highly skilled experts and often involves complicated processes. Qualitative information yields results based on preset parameters for the analysis and qualitative evaluation of the parameters. Therefore, the reliability of the information is relatively low, but the analysis can be simple and quick.

Below we briefly discuss commonly used environmental assessment tools. The LCA, MET points, and simplified LCA will be the tools utilized for the assessment of environmental issues, while environmental benchmarking and EQFD will be used to assess stakeholder requirements.

2.1 Tools for the identification of environmental issues

Life cycle assessment

Life cycle assessment is best known for quantitative analysis of the environmental aspects of a product over its entire life cycle stages. An LCA is a systematic tool that enables the analysis of the environmental loads of a product throughout its entire life cycle, as well as the potential impacts of these loads on the environment. Products in this context include both products and services. Emissions to the air, water, and land such as CO_2, BOD, solid wastes, and resources consumptions constitute environmental loads. Environmental impacts in the LCA context refer to adverse impacts on an area that should be safeguarded, such as the ecosystem, human health, and natural resources.

There are four phases in an LCA; goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and life cycle interpretation. (ISO 1997) A brief description of each phase follows.

Why perform an LCA, who are the target audiences, and what should be the product of an LCA study? These are the questions to be addressed by goal definition. Scope definition includes defining product system boundary, functional unit, and data parameters, among others.

Once the product system boundary has been set for each unit process the input of materials and energy and the output (such as products, co-products and emissions) are collected and then normalized to the main output mass. Eventually the life cycle inventory results for the product system is obtained by summing all fractional contributions of the inputs and outputs from each unit process. Thus, the LCI generates quantitative environmental load information of a product in its entire life cycle.

Environmental impacts resulting from the environmental loads of a product system are assessed in the life cycle impact assessment. To quantify the impact, impact categories are first chosen. Then environmental impacts are quantified based on the chosen impact categories and analyzed through the equivalency approach. This process is termed characterization. Performing normalization and weighting impact values can further process the impact information. LCIA thus provides environmental impact information for the product.

The last phase in an LCA study is life cycle interpretation where environmentally significant issues are identified and the LCA results are assessed with respect to completeness, sensitivity and consistency. In addition, conclusions, recommendations and reporting are also part of this phase.

The identified key environmental issues become the starting point for product improvement. The concept of a product that fulfills a specific function can be generated from the key environmental issues. This process is an integration of the environmental aspects into product design and development, or ecodesign. Based on the concepts generated from the key environmental issues, detailed design and layout of the product can be completed, and an eco-product is produced.

Once eco-products are produced, the improved environmental aspects of the eco-product must be communicated to the market with the hope that the newly developed eco-product will increase its market share or reduce product cost. These are the most likely incentives for the manufacturer to design and develop eco-products. For this reason, environmental product declarations that communicate environmental aspects of a product to the purchasers are an essential element of the eco-product development. This is clearly one of the major objectives for performing an environmental assessment such as the LCA. Other applications of LCA include strategic planning, public policy making, marketing, and other applications (ISO 1997).

The MET points method

In general, it is rather complicated to apply LCA results directly to the product design and development processes by the product designer. This is mainly because there is superfluous information from the LCA results. To overcome this hurdle a method that presents LCA results in a simplified form can often be used. The MET points method broadly classifies impact categories into three main groups; material cycles (M), energy use (E), and toxic emissions (T).

In regards to the MET, resource consumption represents the material cycle's (M) group. In addition the formation of greenhouse gases or global warming, acidification, photochemical oxidant creation (smog), and eutrophication belong to the energy use (E) group. And finally, the toxic emissions (T) group includes ozone layer depletion, human toxicity and eco-toxicity. Under each group, a normalized or weighted impact value of each impact category is summed to represent the overall impact of each group.

Table 2.1 shows an example of the MET points method.

Table 2.1 Example of the MET points (Kalisvaart and Remmerswaal 1994)

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

As Table 2.1 exemplifies, the MET points method simplifies the LCA results by aggregating the different impact categories into three groups. The product designers can thus easily identify areas for improvement of their products based on the aggregated impact results. In essence, the method is built upon the LCA results. The main function of the method is to aid product designers focusing on one of the three groups. For the example shown in Table 2.1, the energy group is the point of departure for product designers incorporating it into the product design.

Simplified life cycle assessment

Implementing the LCA for products has been criticized mainly from industry users as being too time consuming and costly. The purpose of the simplified LCA is to address these criticisms of the LCA by simplifying the LCA procedures. The simplified LCA, however, contains two elements that could be construed as contradictory. They are the assessment of the environmental impact of a product throughout its entire life cycle with accuracy, and the minimization of the cost and time required for the assessment (Christiansen et al 1997). The key to the success of the simplified LCA therefore lies in the simplification of the first stage of the LCA- defining the goal and scope phase. By simplifying this stage one can reduce the complexity of the product system boundary relevant to the goal of the LCA study.

Simplification can be classified into two different approaches: one is the approach that reduces the effort required for the data collection (quantitative) and the other is the qualitative approach. Use of similar data, omitting certain life cycle stages, and exclusion of particular inventory parameters are examples of the quantitative approach.

The latter approach includes, among others, focusing only on particular types of environmental impacts or issues.

Table 2.2 lists six different simplified approaches. Depending on the needs of the product development team one of the six different approaches can be chosen for the identification of key environmental aspects of the product for ecodesign.

2.2 Tools for assessing stakeholder requirements

Environmental benchmarking

Benchmarking is a method that systematically extracts information for the improvement of a product by comparing specific parameters of a product against those of the competitor's products (Codling 1992). Environmental benchmarking is a modification of a conventional benchmarking method where only environmental parameters are compared. We will explain principles of benchmarking, in particular environmental benchmarking, using the method proposed by the electronics manufacturer Philips.

At Philips, a total of five major parameter groups, also termed focal areas, were chosen for environmental benchmarking. They are; energy, toxic chemicals, recyclability, weight, and packaging. Figure 2.1 depicts procedures taken at Philips when implementing environmental benchmarking.

Step One: Choose a product for environmental improvement to be benchmarked against three or four products from competitors. Step Two: Select specific benchmarking parameters belonging to the five main parameter groups, in this book we refer to these parameters as environmental parameters. Step Three: Implement benchmarking by comparing the incumbent's own product against competitors products for all chosen environmental parameters. Step Four: Identify environmental parameters where the incumbent's own product performance is inferior to those of its competitor's products. These inferior environmental parameters reflect weak points of ones own product, and become starting point for improving environmental aspects of a product.

Table 2.2 Simplified approach (Todd et al 1999)

Simplified approach	Application procedure
Removing upstream components	All processes prior to final materials manufacturing are excluded. This includes fabrication into a finished product, consumer use, and post-consumer waste management. Application: When environmental impacts from manufacturing, use and disposal stages are dominant compared to the upstream processes.
Removing downstream components	All processes after final materials manufacturing are excluded. Application: When the aim of ecodesign is to improve environmental performance of a product by replacing raw and ancillary materials, or the environmental impacts from use and disposal stages are considered low or nil.
Removing up- and downstream components	Only primary material manufacturing is included, as well as any pre-combustion processes for fuels used in manufacturing. Sometimes referred to as a "gate-to-gate" analysis. Application: When focus is given to the identification and improvement of environmental aspects of a company related to its manufacturing processes.
Using specific entries to represent impacts	Selected entries are used to approximate results in all impact categories, based on mass and subjective decisions; other entries within each category are excluded. Application: When a company considers only specific environmental impact categories of the products significant.
Using qualitative or less accurate data	Only dominant values within each of several major process groups are used; other values are excluded, as are areas where data can be qualitative, or otherwise of high uncertainty. Application: When quantitative data collection is impossible, use qualitative data instead.
Using surrogate process data	Selected processes are replaced with apparently similar processes based on physical, chemical, or functional similarity to the datasets being replaced. Application: When data of specific components and process cannot be collected and thus use data from the similar components and processes is used instead.

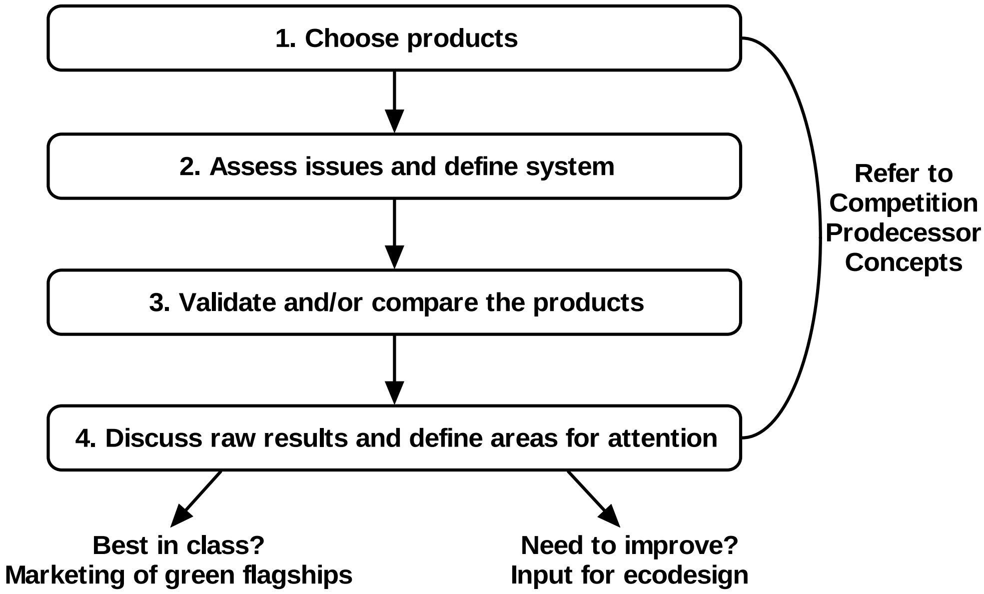

Figure 2.1 Environmental benchmarking procedure at Philips (Deckers et al 2000)

Environmental quality function deployment (EQFD)

Quality Function Deployment (QFD) is a product design process where consumer needs are reflected in product design attributes. This process is mainly applied to extract design parameters focused on product quality (ReVelle et al 1998).The Environmental Quality Function Deployment is a modification of QFD by limiting consumer needs only to environmental aspects. Below we explain the EQFD method proposed by the Japan Environmental Management Association for Industry (JEMAI). Figure 2.2 shows implementation procedure of EQFD.

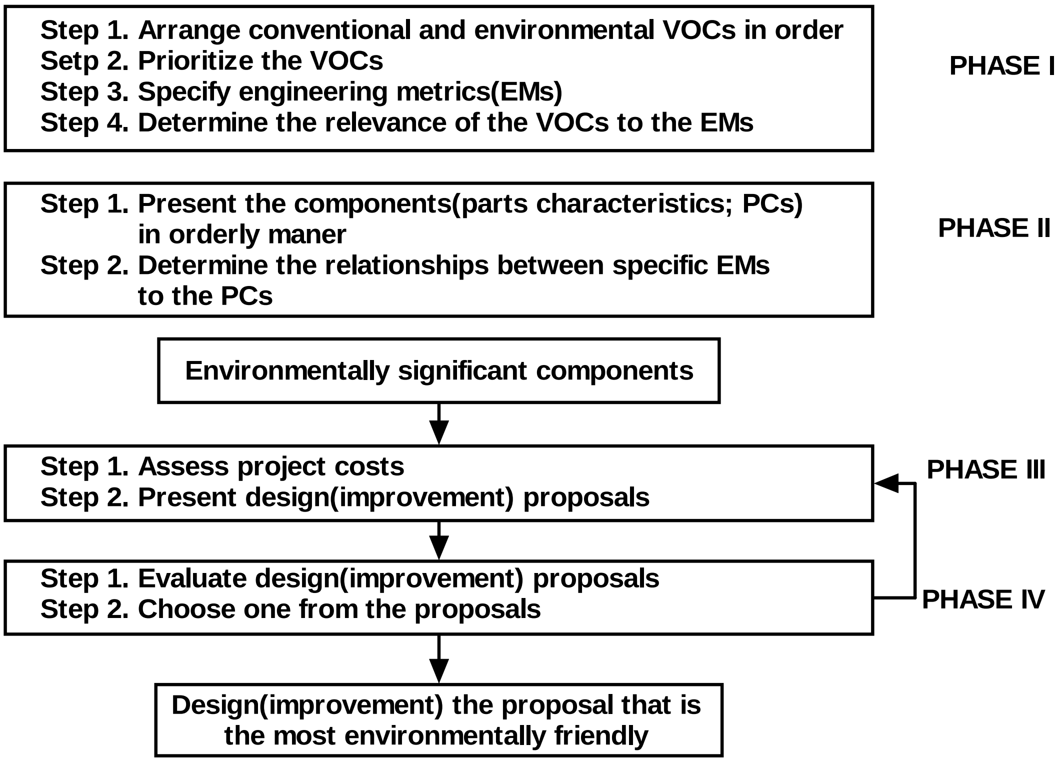

Figure 2.2 Flow of QFDE-Based DfE (JEMAI 2001)

Of the four phases, environmentally significant components of a product are identified in Phase I and Phase II. In addition, environmentally effective design alternatives are obtained in Phase III and Phase IV. In the case of Wimmer et al (2004), they applied EQFD to the identification of significant environmental parameters originating from the legal requirements and/or eco-labeling requirements using only the step stated in phase I. In turn, since our interest is to identify environmentally significant stakeholder requirements and then transform them into environmental parameters, we will focus our effort on Phase I only.

Phase I consists of four elements. In the first element, the task is to define stakeholder requirements in the form of conventional VOC (voice of customer) and environmental VOC. Here the JEMAI defined a total of 11 environmental VOC based on product related environmental regulations. In the second element, relative significance of environmental VOC is assigned. In the third element, environmental metrics or environmental parameters are defined. Lastly, the relationship between environmental VOC and environmental metrics or parameters is determined by assigning relative figures.

2.3 Comparison among different environmental assessment tools

The environmental assessment tools for ecodesign should be easy to use, take less time, cost less to get the results, and generate objective and accurate results. Ha (2001) lists the specifics for each of these requirements.

- Cost and time: Environmental aspect is an additional feature added to the existing product features including function, performance, cost and ergonomics, among others. Technological innovation leading to shorter product life cycles and thus shorter product development times is a must in today's market. Thus, it is impractical spending excessive amount of money and time for the analysis of the environmental aspects of a product. Accordingly, time and cost must be minimized for the environmental assessment of a product.
- Design applicability: One of the most important elements in ecodesign is the identification of the opportunities for improving environmental performance of a product and selection of the appropriate alternatives to achieve improved environmental performance. Identification of potential improvement opportunities are based on the environmental assessment results. Thus, the identified environmental improvement opportunities should be prepared in a manner that is easy to understand and easy to generate improvement alternatives by product designers.

Objectivity and accuracy: The fundamental nature of the identified improvement opportunities must be based on objective and accurate information. Inaccurate and subjective environmental assessment results may well lead to inferior products in environmental performance compared to the previous referenced product. Table 2.3 shows the evaluation results of the five environmental assessment methods based on the three criteria listed above.

Table 2.3 Evaluation of environmental assessment tools

Tools \ Criteria	Cost and time	Design applicability	Objectivity and accuracy
LCA	--	+/-	++
The MET points method	--	+	++
Simplified LCA	+/-	+/-	+
Environmental benchmarking	+	++	+/-
EQFD	--	++	+

++ : Very good, + : Good, +/- : Moderate, - : Little, -- : Very little

LCA is superior in objectivity and accuracy. However, it has drawbacks in respect to cost and time. This drawback exists because it requires extensive data collection efforts required to analyze all life cycle stages of a product. The MET points method is similar to LCA in respect to cost/time and objectivity/accuracy, for it is also based on the LCA results. However, presenting results in a way that is easy to understand for product designer makes this method superior to the LCA method in design applicability. Simplified LCA methods are superior compared to the LCA method in respect to cost/time, but inferior in respect to objectivity/accuracy. For efficient and effective identification of significant environmental issues of a product, we recommend using the simplified LCA method.

Design applicability of the environmental benchmarking method is very good, and the information provided by this method is objective and accurate. Meanwhile, the cost and time aspects of the EQFD method are inferior, while the design applicability and objectivity/accuracy are superior. Since both the environmental benchmarking and EQFD methods are intended for assessing stakeholder requirements, there is no need to discern which one is superior to the other.

3. ECODESIGN STRATEGIES

Ecodesign strategy provides guidance in generating ecodesign tasks that are implementation measures for reducing environmental impacts originating from a product. Thus, the selection of the right ecodesign strategies is instrumental to the success of ecodesign. There are three widely known sources for ecodesign strategies. They are the life cycle design guidance manual, the UNEP/promising manual, and the Thompson approach.

Ecodesign strategies provide guidance in generating practical measures for improving the environmental performance of a product. Ecodesign strategies in each of the three sources stated above are all empirical in nature, not theoretical. Although the sources vary in name, they all share a common underlying strategy. This can be confusing when it comes to the selection of a specific ecodesign strategy. Thus, selection of relevant ecodesign strategies is indispensable for implementing ecodesign.

Below is a brief introduction of ecodesign strategies in each of the three sources.

3.1 Ecodesign strategies in the life cycle design guidance manual

Table 3.1 lists generic as well as specific ecodesign strategies discussed in the life cycle design guidance manual. Each of the seven generic ecodesign strategies has several specific ecodesign strategies.

Table 3.1 Generic and specific ecodesign strategies in the life cycle design guidance manual (Keoleian and Menerey 1993)

Generic strategies	Specific strategies
Product system life extension	Appropriately durable Adaptable, Reliable Serviceable (Maintainable, Repairable) Remanufacturable, Reusable
Material life extension	Types of recycled material Recycling pathways Infrastructure, Design considerations
Material selection	Substitution, Reformulation
Reduced material intensiveness	None
Process management	Process substitution (Process energy efficiency, Process material efficiency) Process control Improved process layout Inventory control and material handling Facilities planning Treatment and disposal
Efficient distribution	Transportation Packaging (Packaging reduction, Material substitution)
Improved management practices	Office management Phase out high impact products Choose environmentally responsible suppliers or contractors Information provision (Labeling, Advertising)

3.2 Ecodesign strategies in the UNEP/promising manual

Table 3.2 lists generic and specific ecodesign strategies proposed in the UNEP/promising manual. As shown in Table 3.2, generic ecodesign strategies are classified into different product levels. The three levels are, the product component level, the product structure level, and the product system level. Generic ecodesign strategies are related to a certain product life cycle stages as shown in Figure 3.1. The figure also shows major impact areas affected in a given life cycle stage.

Table 3.2 Generic and specific ecodesign strategies in the UNEP/promising manual (Brezet and Hemel 1997)

	Generic strategies	Specific strategies
-	New concept development	Dematerialization Shared use of the product Integration of functions Functional optimization of the product (components)
Product component level	Selection of low impact materials	Cleaner materials Renewable materials Lower energy content materials Recycled materials Recyclable materials
	Reduction of materials usage	Reduction in weight Reduction in (transport) volume
Product structure level	Optimization of production techniques	Alternative production techniques Fewer production steps Lower/cleaner energy consumption Less production waste Fewer/cleaner production consumables
	Optimization of distribution system	Less/cleaner/reusable packaging Energy-efficient transport mode Energy-efficient logistics
	Reduction of impact during use	Lower energy consumption Cleaner energy source Fewer consumables needs Cleaner consumables No waste of energy/consumables
Product system level	Optimization of initial lifetime	Reliability and durability Easier maintenance and repair Modular product structure Classic design Strong product user relation
	Reduction of end of life system	Reduction in weight Reduction in (transport) volume

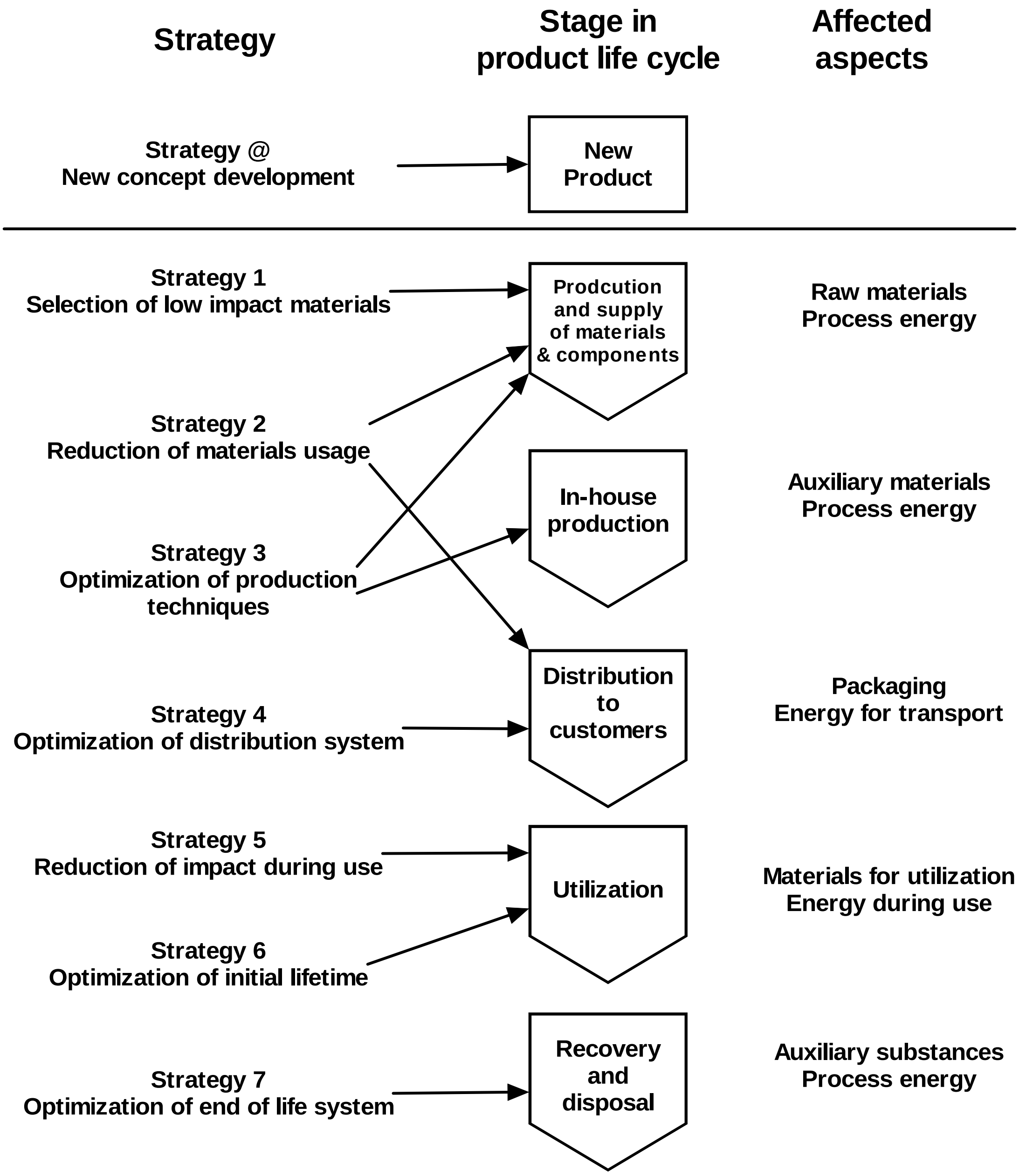

Figure 3.1 Relation between ecodesign strategies and product life cycle (Brezet and Hemel 1997)

3.3 Ecodesign strategies in the Thompson's approach

Table 3.3 lists generic ecodesign strategies proposed by Thompson (1999) together with the underlying principle of each strategy. The principles may be considered implementation measures to realize corresponding generic ecodesign strategy.

Table 3.3 Generic ecodesign strategies and principles in the Thompson's approach (Thompson 1999)

Generic strategies	Principles
Materials management	Minimize the amount of material in each part
	Lengthen the service life
	Specify recycled materials whenever possible
	Specify energy efficient materials in the product/service
	Specify materials that pollute minimally during their extraction manufacturing, use and disposal
	Specify readily available materials that do not deplete declining natural resources
	Specify materials that are unlikely to be affected by new legislation that will constrain their deployment, manufacturing, or disposal
Minimize material utilization	Minimize the number of different materials in a part Select easily recycled materials
	Ensure easy product disassembly
	Facilitate material identification
Recycling materials	Minimize the variety of materials in a product
	Consolidate parts
	Reduce the number of assembly operations
	Specify compatible materials
	Simplify and standardize fits
	Identify separation points between parts
	Specify water soluble adhesives
	Incorporate a material identification scheme on parts to simplify identification
Extend the service life	Create a user-friendly document for repair and maintenance
	Ensure that the life cycle is environmentally optimal
	Replace worn parts
	Replace parts with a new generation of parts
	Identify the inherent weaknesses in a product and redesign to avoid premature failure
	Identify potential hazards associated with the product at the end of it's service life and minimize them
	Use design for disassembly principles to facilitate the remanufacture and recycling of parts
Energy utilization	Minimize energy consumption
	Minimize energy losses

4. ECODESIGN METHOD

As discussed in chapter 1, significant environmental aspects of a product in its entire life cycle and stakeholder requirements must be identified. Next, one can determine the significant environmental parameters, in the form of benchmarking parameters or checklist parameters, to be considered in the product design. The identified significant environmental parameters are then linked to ecodesign strategies, which in turn lead to the generation of ecodesign tasks or ideas.

Based on the discussions in chapters 1, 2 and 3, we proposed an ecodesign method applicable to an electronics product group. Figure 4.1 shows the ecodesign method we proposed in this book. It consists of five modules. They are: life cycle thinking, environmental benchmarking, the checklist method, ecodesign strategies, and ecodesign information.

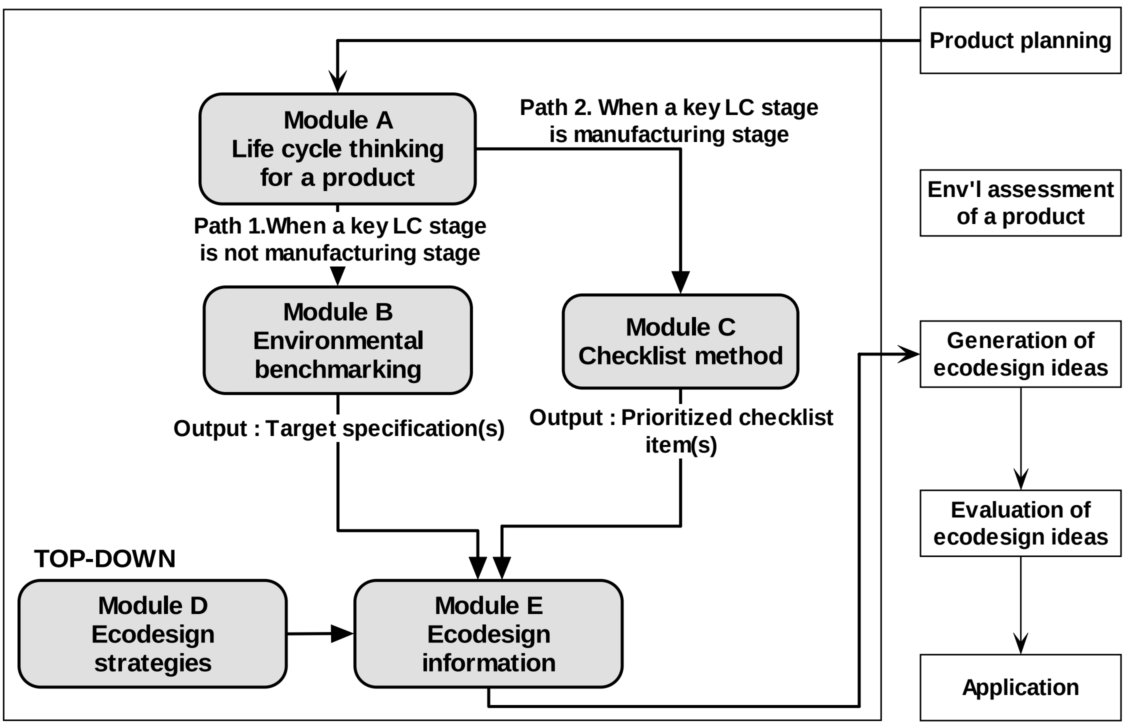

Figure 4.1 An ecodesign method for electronic products

Module A in figure 4.1 identifies only key life cycle stages of a product that most impact the environment. This is to minimize the time and cost for the identification of significant environmental parameters by focusing all identification efforts on the most significant life cycle stage.

Depending on the identified key life cycle stage, identification of significant environmental parameters of a product follows two different paths. If the identified key life cycle stage is one of the four life cycle stages other than the manufacturing stage (i.e., raw material acquisition, distribution, use, and end of life), module B (environmental benchmarking) follows. If the identified key life cycle stage is manufacturing, then module C (checklist method) follows.

Based on the key environmental parameters derived from modules B or C, ecodesign strategies corresponding to the relevant environmental parameters are chosen. Module D (ecodesign strategies) provides all the ecodesign strategies applicable to electronic products. Module E (ecodesign information) lists ecodesign strategies linked to the significant environmental parameters (benchmarking parameters) and checklist parameters.

Below is a detailed description of each of the five modules with respect to what they are and how to use them in the context of implementing ecodesign.

4.1 Life cycle thinking

Products exert impacts on the environment throughout its entire life cycle, i.e., raw material acquisition, manufacturing, distribution, use and end of life. However, the magnitude of the impacts differs from life cycle stage to stage. Thus it is economical and practical to concentrate improvement efforts on a life cycle of which environmental impacts is the greatest. For this reason identification of the most significant life cycle stage of a product is the first task implemented in the proposed ecodesign method (see Figure 4.3)

Environmental assessment methods geared at product level in Chapter 2 are then used to identify significant life cycle stages. We recommend using a simplified LCA method. If this is not feasible, one can use a quick assessment method using commercially available software for rough analysis. Alternatively, one may use a web-based free software named PILOT (product investigation, Learning and Optimization Tool for sustainable product development) Assistant (Wimmer 2002) The PILOT ASSISTANT program asks for product information inputs and in turn generates key life cycle stage output.

4.2 Environmental benchmarking

Successful environmental benchmarking requires proper choice of benchmarking parameters or environmental parameters. Without parameters, no comparison against competitor's products can be possible. Below is a description of the implementation issues related to benchmarking and a method for setting up environmental improvement targets.

Benchmarking parameters

In this section, detailed descriptions of the process choosing environmental benchmarking parameters and implementation methods of environmental benchmarking for the identification of weak points of a product are delineated. The first step is to choose environmental benchmarking parameters and arrange them in life cycle stages.

Table 4.1 lists common environmental parameters used by major corporations in the world. The information in this table came from environmental reports of those corporations.

Based on information in Table 4.1, we derived a total of 31 environmental benchmarking parameters together with measurement method of each parameter of which are shown in Table 4.2. The benchmarking parameters are grouped in four life cycle stages: raw material acquisition, distribution, use, and end of life.

Table 4.1 Environmental parameters for environmental aspects evaluation by major corporations

Company	Environmental parameters for evaluating environmental aspects
Philips	Weight, hazardous substances, energy consumption, recycling and disposal, packaging
Siemens	Hazardous substances, raw material and energy consumption, waste minimization
IBM	Material recovery, energy efficiency, packaging, source reduction, hazardous substance
Hewlett -Packard	Energy consumption, less material, recyclable material (packaging), reuse and recycle
Toshiba	Electricity consumption, weight, recyclability, packaging
Sony	Energy consumption, water consumption, packaging, hazardous substance, waste generation
Nokia	Energy intensity, material intensity of goods and services, toxic dispersion, recyclability, use of renewable resources, product durability, total efficiency in process

Table 4.2 Environmental benchmarking parameters and their measurement methods

Life cycle stage	Environmental benchmarking parameter	Attribute	Measurement methods
Raw material acquisition	Hazardous material content (if measurable)	-	Use analytical instruments for measuring hazardous substances.
	Marking of hazardous components	+	Check the marking of the hazardous substance on a product.
	Surface area of PCB	-	Measure surface area of PBC for the same layer of PCB.
	Number of components on PCB	-	Count the number of components mounted on a PCB by distinguishing the number of Integrated Circuit (IC) chips and other components.
	Surface area of LCD	-	Measure surface area of the LCD.
	Ratio of weight/length cable (or wiring)	-	Measure length and weight of a cable and calculate a ratio between length and weight.
	Weight of packaging material	-	Measure weight of packaging.
	Weight	-	Measure weight of a product.
	Number and weight of accessory parts	-	Measure weight of accessory parts and count the number of accessory parts.
	Number of types of material	-	Count the number of types of materials of a product.
	Number of parts	-	After disassembling products to all disassemblable parts, count the number of the disassembled parts.

Distribution	Weight and number of users manual	-	Measure weight of product user manuals and count the number of manuals.
	Ratio of packaging weight/product weight	-	Measure weight of a product and packaging and calculate the ratio between packaging weight and product weight.
	Volume of packaging box	-	Measure volume of a packaging.
	Weight of total product (including packaging)	-	Measure combined weight of a product and packaging.
	Volume of total product (including packaging)	-	Measure combined volume of a product and packaging.
Use	Amount of consumable needed	-	Estimate the amount of consumables during the use stage of a product.
	Stand-by mode energy consumption	-	Measure stand-by mode electricity consumption.
	Operational mode energy consumption	-	Measure operational mode electricity consumption.
	Charger energy efficiency	+	Measure charge mode electricity consumption.

End of Life	Recycled material content	+	If a product contains recycled content, find the recycled content information.
	Recyclable material content	+	If a product is recyclable, estimate the amount of recyclable materials.
	Reusable part	+	If a product is reusable, estimate the amount of materials for reusable parts.
	Number of joints	-	Count the number of joints between components.
	Number of tools for disassembly	-	Count the number of tools needed for disassembly of a product.
	Disassembly time	-	Measure average time for disassembly of a product by an experienced technician.
	Number of types of joints	-	Count the type of joints between components.
	Number of parts	-	After disassembling products to all disassemblable parts, count the number of the disassemble parts.
	Marking of materials	+	Count the number of material declaration markings of all parts and components in a product.
	Number of types of material	-	Count the number of types of material in a product.
	Warranty period	+	Record warranty period of a product.

- : Negative parameter, + : Positive parameter

Depending on the attribute of each parameter, either a positive or negative sign is given to each parameter, and denoted as "+" or "–". A negative (-) parameter indicates that the smaller the measure value is, the better the environmental performance is. Parameters such as product weight, material quantity, number of components, and energy consumption are examples of the negative parameters. A positive parameter (+) indicates that the greater the measured value is, the better the environmental performance is.

Implementation of environmental benchmarking

Figure 4.2 shows an environmental benchmarking implementation procedure. The implementation procedure is based on the 5W1H (Why, When, Who, Where, What, and How) in combination with the PDCA (Plan, Do, Check, Act) cycle.

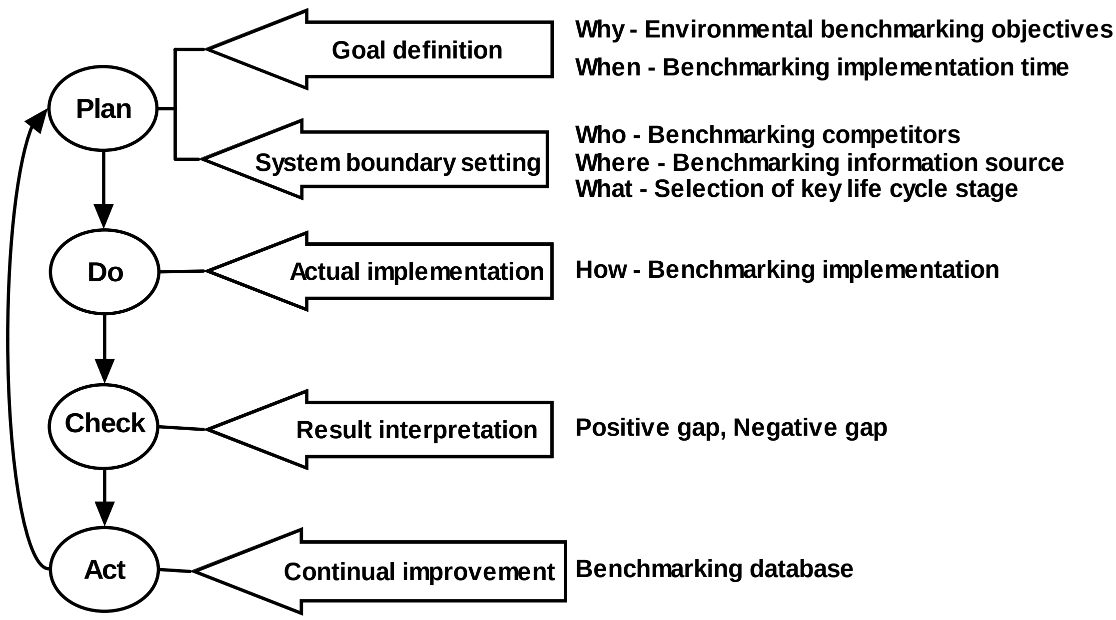

Figure 4.2 Environmental benchmarking procedures with the PDCA cycle (Yim and Lee 2002)

Plan in Figure 4.2 is a step that sets up the goal of environmental benchmarking and boundary of the benchmarking or system boundary setting. *Why* and *when* belong to the goal definition. *Who, where* and *what* belong to the system boundary setting. *Do* in Figure 4.2 is a step that implements benchmarking. This step is equivalent to *How*. *Check* in Figure 4.2 is a step that analyses the benchmarking implementation results. *Act* is a step that manages the benchmarking results in the benchmarking database for further product design activities in a company. Below is a detailed description of the 5W and I H for implementing benchmarking.

- Why (purpose of implementing benchmarking): Define the purpose of implementing benchmarking in specific terms. Examples of the purposes include: increase awareness of consumers in the environmental improvements of a product, increase profit through applying ecodesign to product development, and continual environmental improvement of a corporation, among others (Codling 1992).
- When (Implementation duration): Benchmarking is a part of product development process. Thus, timing and duration of its implementation must be framed within a time schedule of product development.
- Who (target products for benchmarking): In general, 3 to 4 competitor products are chosen as target products. Factors to consider in choosing the target products include sales price, function, performance, size, and market share of the products.
- Where (Sources of benchmarking information): Sources of information for benchmarking include: internal experts and external information sources (competitor websites and libraries).
- What (Selecting target life cycle and benchmarking parameters): Select target life cycle from the life cycle thinking for a product. Once a target life cycle is chosen, corresponding benchmarking parameters are chosen. Depending on the specific features of a product, additional parameters can be added or deleted from the list if irrelevant.
- How (Implementing benchmarking): How to perform benchmarking is a key to benchmarking. Actual comparison and measurement are made in this step.

Determination of environmental targets

Based on the environmental benchmarking results per parameter, environmental targets of one's product are determined. The improvement targets are set after checking against three criteria; legal requirements, benchmarking results of the competitor's products and environmental target of one's own company. Figure 4.3 shows a procedure for setting the environmental improvement targets.

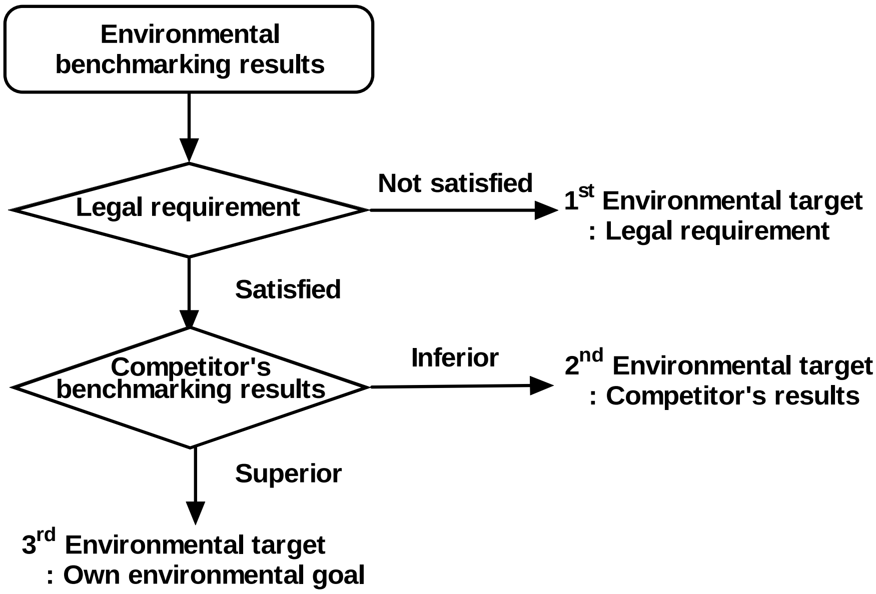

Figure 4.3 Determination of environmental improvement targets using benchmarking results

The first step is to check whether one's own product meets legal environmental requirements. If not, those legal requirements become primary targets for environmental improvements. The next step is to choose weak points (environmental parameter or benchmarking parameter) of one's own product compared against the competitor's products. Based on these weak points or parameters one can set up targets for environmental improvements. Lastly, one's own environmental target can be set for parameters even where the product performs better than the competitor's products.

Both negative parameters and positive parameters employ different formulae for setting up environmental improvement targets. In the case of negative parameters, targets for environmental improvements is set using a formula shown in Equation (1)

$$\frac{(X\text{-}Y)}{X} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where,

X = environmental performance of own product,

Y = environmental performance of competitor's product or own target

In the case of positive parameters, target for environmental improvements is set using a formula shown in Equation (2)

$$\frac{(Y-X)}{X}\times 100 \qquad (2)$$

4.3 Checklist method

In this section, a description of the checklist evaluation parameters and evaluation methods are delineated.

Checklist parameter

Checklist parameters were developed based on all inputs, (including ancillary materials and energies) and outputs (including wastes and emissions to air and water) associated with the manufacturing of a product. Note that raw material inputs and products, or co-products, were not included in the checklist parameters because problems in the manufacturing process come only from the use of materials and the generation of emissions within the manufacturing processes only.

Table 4.3 lists checklist parameters, most of them came from existing literatures (Wimmer 2002, Brezet and Hemel 1997, Clark and Charter 1999).

Table 4.3 Checklist parameters for the manufacturing stage

Category	Checklist parameter
Ancillary material	Preferably use ancillary materials from renewable raw materials
	Recycle ancillary materials whenever possible
	Use environmentally acceptable ancillary materials
	Avoid hazardous ancillary materials
Energy	Use energy efficient production technologies
	Reduce energy consumption by optimum process design
	Preferably use renewable energy resources
	Minimize overall energy consumption in the production site
Waste	Use low emission production technologies
	Avoid environmentally hazardous production technologies
	Avoid waste in the production process
	Close material cycles in the production process
	Recycle/reuse waste for new materials
	Dispose of unavoidable waste in an environmentally acceptable manner
	Waste sorting/separation whenever possible
Emission	Avoid environmental emissions in the production process

Checklist evaluation method

Evaluation of checklists follows a method developed by Wimmer (2002). His method uses three criteria for evaluation: weighting, implementation status within a company, and the degree of implementation risks. From the evaluation, one determines the important checklist parameters. Details of the evaluation method modified by the authors are:

- Weighting: Assign a relative weight to a product: 10 points for high significance, 5 for medium significance, and then 0 for no importance.
- Implementation status within a company: If already implemented, assign 1 point. If it is not properly implemented but implemented nonetheless, assign 2 points. If not implemented but, considered implementing in the near future, assign 3 points. If no plans for implementation exist assign 4 points.
- Implementation risk: When implementation risk is high, assign 30 points, when it is low, assign 10 points, between these two risk factors, assign 20 points.

Priority is defined as a product between weight and implementation status within a company. The highest value of priority is 40 and the lowest is 0. Plotting priority and implementation risk as shown in Figure 4.4 (Wimmer 2002) and can be used to evaluate checklist parameters. This measurement becomes the basis for choosing parameters for implementing environmental improvements.

Figure 4.4 shows that region 1 represents an area where checklist parameter must be implemented as early as possible for environmental improvement, for it has low implementation risk and high priority. Region 2 represents an area where checklist parameter needs to be implemented in the future. Region 3 portrays conditions where there is no need to consider the parameter for environmental improvement.

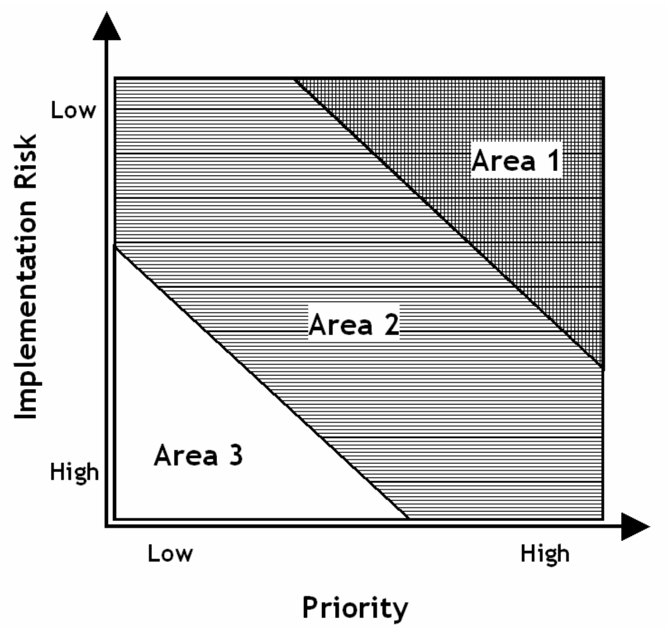

Figure 4.4 Portfolio on the evaluation of implementation measures (Wimmer 2002)

4.4 Ecodesign strategies

Ecodesign strategies were grouped in three attributes: product related, material related and energy related. This grouping was intended for the ease of generating ecodesign tasks or ideas in later steps of development, i.e., module E.

The first attribute (product related) is related to the structure and characteristics of a product. The second attribute (materials related) is related to the materials used in the product. The third attribute (energy related) is related to the energy consumption in the manufacturing and use stages of the product. Each of the three attributes includes specific attributes and actual ecodesign strategies. In the case of product related attributes, specific attributes include product use, end of life and product lifetime. There are a total of nine ecodesign strategies in the product related attribute, and they are connected to corresponding specific attributes.

Table 4.4 lists a total of 25 ecodesign strategies applicable to electronic products group. Detailed descriptions of each of the 25 strategies together with examples are depicted in Appendix B.

Ecodesign strategies have two areas of application. One is to provide guidance in generating ecodesign tasks or ideas by the product designer. In this case, significant environmental parameters derived from the environmental benchmarking or checklist methods are linked to relevant ecodesign strategies. The product designers then generate creative ideas based on the guidance given by the ecodesign strategies. The other is to use the ecodesign strategies for educating product designers and developers in ecodesign.

Table 4.4 Ecodesign strategies applicable to electronic products group

Attribute		No	Ecodesign strategy
Product related	Use	1	Indication of resource/energy consumption in use stage
		2	Materials labeling including instructions for disposal
	End of life	3	Easy disassembly
		4	Inclusion of disposal instructions for end users
	Life time	5	Easy maintenance and repair
		6	Easy upgradeability
		7	Environmentally friendly surface design
		8	Function integration
		9	Standardization of components
Material related	Use	10	Avoidance/reduction of the use of toxic substances
		11	Minimization of process materials in use stage
		12	Reduction of material input
		13	Reduction of the number of materials/parts
		14	Reuse of refurbished parts and components
		15	Use of lower energy content materials
		16	Use of recyclable materials
		17	Use of recycled materials
		18	Use of renewable materials
	End of life	19	Minimization of waste/environmental emissions
		20	Waste recycling/reuse
	Packaging	21	Optimization of the weight/volume of packaging
		22	Use of reusable packaging
Energy related	Use	23	Minimization of energy consumption in use stage
		24	Minimization of energy consumption in production stage
		25	Use of renewable energy resources

4.5 Ecodesign information

Significant environmental parameters in the form of benchmarking parameters or checklist parameters are linked to appropriate ecodesign strategies. The linked information is called ecodesign information and is the basis for generating actual ecodesign tasks or ideas by product designers and developers.

Table 4.5 lists ecodesign strategies related to benchmarking parameters. Table 4.6 lists ecodesign strategies related to checklist parameters. As shown in both tables, a single environmental parameter is linked to one to six ecodesign strategies. This indicates that there can be more than one strategy applicable to improving the environmental aspects of a product represented by the significant environmental parameters.

Table 4.5 The relationship between benchmarking parameter (significant environmental parameter) and ecodesign strategies

Life cycle	Benchmarking parameter	Ecodesign strategy
Raw material acquisition	Hazardous material content	Avoidance/reduction of toxic materials
	Marking of hazardous components	Materials labeling; including instructions for disposal
	Surface area of PCB	Function integration
		Standardization of components
	Number of components on PCB	Function integration
		Reduction of the number of materials/parts
	Surface area of LCD	Reduction of material input
	Ratio of Weight/Length cable (or wiring)	Reduction of material input
		Use of lower energy content materials
	Weight of packaging material	Optimization of the weight/volume of packaging
		Reduction of material input
		Use of lower energy content materials
	Weight of product	Reduction of material input
		Reduction of the number of materials/parts
		Use of lower energy content materials
	Number and weight of accessory parts	Easy disassembly
		Reduction of material input
		Standardization of components
	Number of kinds of material	Reduction of the number of materials/parts
		Reduction of material input
		Use of lower energy content materials
	Number of parts	Reduction of material input
		Reduction of the number of materials/parts
		Use of lower energy content materials
Distribution	Weight and number of users manual	Optimization of the weight/volume of packaging
		Reduction of material input
		Use of lower energy content materials
	Ratio of packaging weight/product weight	Optimization of the weight/volume of packaging
		Reduction of material input
		Use of reusable packaging
	Volume of packaging box	Optimization of the weight/volume of packaging
		Reduction of material input
		Use of reusable packaging
	Weight of total product including packaging	Optimization of the weight/volume of packaging
		Reduction of material input
		Reduction of the number of materials/parts
		Use of lower energy content materials
	Volume of total product (including packaging)	Optimization of the weight/volume of packaging
		Reduction of material input
		Use of reusable packaging

Use	Amount of consumable needed	Indication of resource/energy consumption along use stage
		Minimization of process materials in use stage
	Stand-by mode energy consumption	Minimization of energy consumption in use stage
		Use of renewable energy resources
	Operational mode energy consumption	Minimization of energy consumption in use stage
		Use of renewable energy resources
	Charger energy efficiency	Minimization of energy consumption in use stage
		Use of renewable energy resources
End of life	Recycled material content	Use of recycled materials
	Recyclable material content	Environmentally friendly surface design
		Inclusion of disposal instructions for users
		Use of lower energy content materials
		Use of recyclable materials
	Reusable part	Easy upgradeability
		Environmentally friendly surface design
		Inclusion of disposal instructions for users
		Reuse of refurbished parts and components
		Standardization of components
		Use of renewable materials
	Number of tools for disassembly	Easy disassembly
		Easy maintenance and repair
		Function integration
	Disassembly time	Easy disassembly
		Easy maintenance and repair
		Inclusion of disposal instructions for users
	Number of types for joints	Easy disassembly
		Easy maintenance and repair
		Function integration
	Number of joints	Easy disassembly
		Easy maintenance and repair
		Reduction of material input
	Number of parts	Reduction of material input
		Reduction of the number of materials/parts
		Use of lower energy content materials
	Marking of materials	Easy disassembly
		Materials labeling including instructions for disposal
	Number of kinds (variety) of material	Reduction of material input
		Reduction of the number of materials/parts
	Warranty period	Easy upgradeability
		Standardization of components

Table 4.6 The relationship between checklist parameter and ecodesign strategies

Category	Checklist parameter	Ecodesign strategy
Ancillary material	Preferably use ancillary material from renewable raw materials	Reduction of material input
		Use of lower energy content materials
	Recycle ancillary materials whenever possible	Waste recycling/reuse
	Use environmentally acceptable ancillary materials	Avoidance/reduction of toxic materials
		Use of lower energy content materials
	Avoid hazardous ancillary materials	Avoidance/reduction of toxic materials
Energy	Use energy efficient production technologies	Minimization of energy consumption in production stage
		Use of renewable energy resources
	Reduce energy consumption by optimum process design	Minimization of energy consumption in production stage
		Use of renewable energy resources
	Preferably use renewable energy resources	Use of renewable energy resources
	Minimize overall energy consumption of production site	Minimization of energy consumption in production stage
		Use of renewable energy resources
Waste	Use low emission production technologies	Minimization of waste/environmental emissions
	Avoid environmentally hazardous production technologies	Minimization of energy consumption in production stage
	Avoid waste in the production process	Minimization of waste/environmental emissions
	Close material cycles in the production process	Waste recycling/reuse
	Recycle/reuse waste for new materials	Waste recycling/reuse
	Dispose of unavoidable waste in an environmentally acceptable manner	Waste recycling/reuse
	Waste sorting/separation whenever possible	Waste recycling/reuse
Emission	Avoid environmental emissions in the production process	Minimization of waste/environmental emissions

5. CASE STUDY: MOBILE PHONES

5.1 Selection of products

The applicability of the ecodesign method proposed in Chapter 4 is evaluated using a mobile phone case study. Five mobile phone models (all of which possess the same functions) were selected for this case study. Three products were made in Korea, and two were made in Europe. We selected mobile phones for two reasons. First, an enormous number of mobile phones are used in the market. Second, while the technical life of a mobile phone is long, its useful life is short, due to rapid technological innovation. As a result, many mobile phones are discarded prematurely.

A phone produced by company XX was chosen as a reference product, and the phones produced by the other Korean companies were selected as competitor products. The reference and competitor products were all made in Korea and were some of the best selling models. In addition, two mobile phones produced by European companies (and sold in Europe) were also considered as competitor products. By including these phones into the analysis we will have the opportunity to compare products in Korea with those in Europe. European companies are known for integrating the environmental aspects of their products into the product design and development stages (Nokia 2002, Quella 2001).

Figure 5.1 Reference and competitive products for case study

5.2 Life cycle thinking for mobile phones

Existing LCA results of a mobile phone (MOCIE 2001) was used to identify key life cycle stages. Figure 5.2 shows the environmental impacts (weighted impact) of each life cycle stage of the reference mobile phone. As shown in Figure 5.2, approximately 59% of all environmental impacts caused by mobile phones derive from the raw material acquisition stage. Other literatures also reported similar results saying that more that 60% of all impacts derives from the raw material acquisition stage (Pfahl 2001, Vallés et al 2001). Thus, the raw material acquisition stage is chosen as the most significant life cycle stage of a mobile phone.

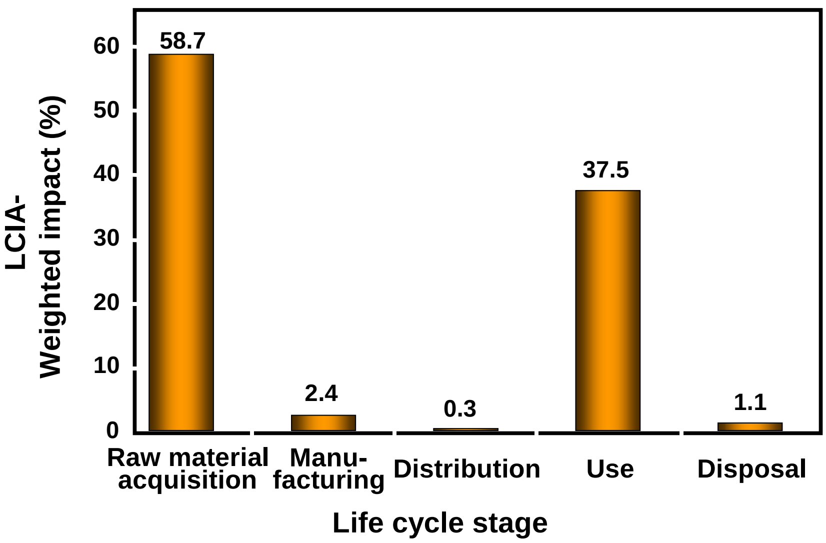

Figure 5.2 LCA results for a mobile phone (MOCIE 2001)

5.3 Environmental benchmarking for mobile phones

A total of 10 benchmarking parameters belonging to the raw material acquisition stage were chosen for implementing benchmarking. Hazardous material content, however, was excluded from benchmarking because of difficulty in measurement. Below are the benchmarking results of each major component. The results include the selection of benchmarking parameters, comparison results and target values for the environmental improvement.

Marking of hazardous components

No markings of hazardous compounds can be found in mobile phones. Hence, the EU regulation entitled "Restriction on the use of certain hazardous substances (RoHS)" has been used to set up the benchmarking parameter. Hazardous substances considered in the benchmarking parameter include cadmium, lead, mercury, hexavalent chromium, Poly Brominated Biphenyls (PBB) and PolyBrominated Diphenyls Ether (PBDE) (CEC 2003b).

Surface area of PCB (Printed Circuit Board)

Figure 5.3 shows PCB of a mobile phone. Since the same type of PCB has been used in all mobile phones compared in the benchmarking process, the amount of hazardous substances used for the manufacturing of PCB is proportional to the surface area of PCB. Thus, surface area of PCB was chosen as the benchmarking parameter.

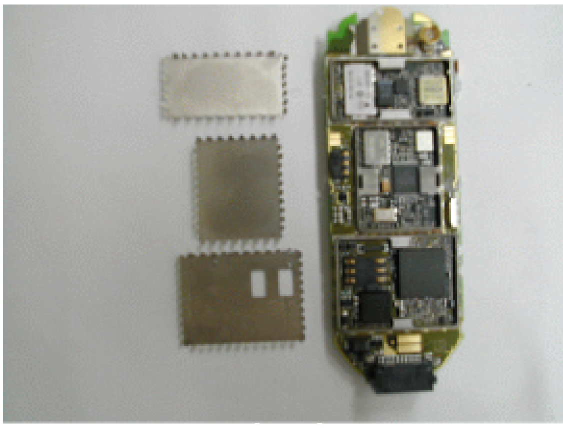

Figure 5.3 Surface area of PCB in a mobile phone

Table 5.1 shows the measurement results of PCB and its respective target for environmental improvements of the surface area of PCB. The surface area of the reference product was the largest of all products compared. Since a smaller surface area is desirable to minimize the environmental impacts of PCB, the target surface area was chosen as the smallest surface area, 30.40cm^2, realized by Competitor 2's product. Thus, the environmental improvement target of the PCB surface area was to reduce surface area of existing PCB by 24% [(40.11-30.40)/40.11].

Table 5.1 Benchmarking results and the environmental improvement target of the surface area of PCB

	Reference	Competitor 1	Competitor 2	European 1	European 2
Surface area of PCB (cm^2)	40.11	32.38	30.40	30.61	32.45
Best			V		
Target	24% reduction				

Number of components on PCB

Integrated circuit (IC) chips are designed to perform integrated functions of individual components such that they are superior to individual components in function and in environmental performance. The number of IC chips and individual components were chosen as a benchmarking parameter.

Table 5.2 shows the measurement results of the number of components on PBC and target environmental improvements. The number of components on PCB of the reference product was fewer among the domestic competitors, but greater against the European competitors. Since a fewer number of components lead to lesser environmental impacts by PCB, the target should be the smallest number of components realized by European 1's product. Thus, an environmental improvement target of a 22% [(259-201)/259] reduction in the number of components on PCB was set.

Table 5.2 Benchmarking results and the environmental improvement target on the number of components on PCB

Components on PCB	Reference	Competitor 1	Competitor 2	European 1	European 2
IC (EA)	43	28	34	19	24
Else (EA)	216	366	275	182	220
Total	259	394	309	201	244
Best				V	
Target	22% reduction				

Surface area of the LCD

Figure 5.4 shows the LCD of a mobile phone. Since the amount of hazardous substances used for the manufacturing of a LCD is proportional to the surface area of a LCD, surface area of the LCD was chosen as benchmarking parameter.

Figure 5.4 LCD of a mobile phone

Table 5.3 shows measurement results of the surface area of the LCD and its environmental improvement target. The reference product's LCD surface area was the largest of all the products compared. Since a smaller surface area is desirable in minimizing the environmental impacts of an LCD, the target surface area was chosen as the smallest surface area, 6.785cm^2, realized by European 1's product. Thus, the environmental improvement target of the LCD surface area was to reduce its surface area by 52% [(14.02-6.785)/14.02].

Table 5.3 Benchmarking results and the environmental improvement target on the surface area of LCD

	Reference	Competitor 1	Competitor 2	European 1	European 2
Surface area of LCD (cm^2)	14.02	10.8	10.5	6.785	10.35
Best				V	
Target	52% reduction				

Ratio of weight/length of charger cable

Figure 5.5 shows the charger portion of a mobile phone. The ratio between length of the charger cable and weight indicates material consumption for the charger; thus, a ratio between the length and weight of the charger cable was chosen as a benchmarking parameter for comparison.

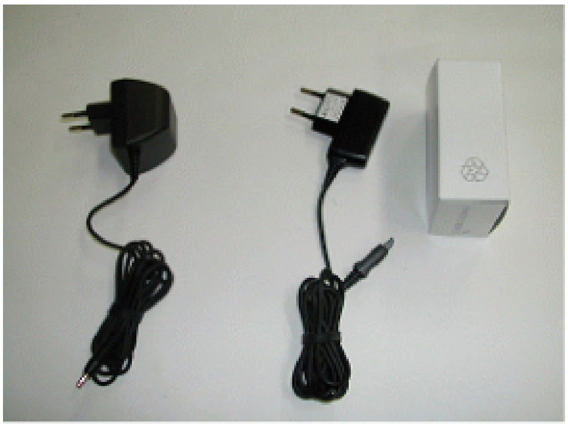

Figure 5.5 Charger of a mobile phone

Table 5.4 shows measurement results of the ratio and its environmental improvement target. The reference product's ratio was the largest among all products compared. This indicates that the material consumption efficiency of the reference product is the lowest among all the products compared. Since a smaller ratio is desirable in minimizing the environmental impacts of a charger cable, the smallest target ratio, 0.14 was chosen. Thus, the reference product's environmental improvement target of the length and weight ratio of the charger cable was to reduce its ratio by 60% [(0.35-0.14)/0.35].

Table 5.4 Benchmarking results and the environmental improvement target of the weight/length ratio of a cable

	Reference	Competitor 1	Competitor 2	European 1	European 2
Ratio of weight/length of cable	0.35	0.14	0.27	0.14	0.14
Weight (g)	55.36	25.28	47.88	29	25.95
Length	155	187	180	205	185
Best		V		V	V
Target	60% reduction				

Weight of packaging material

Figure 5.6 shows the packaging of a mobile phone. Since packaging represents typical environmental problems of a product, the lesser the weight is the better the environmental performance. Thus, the weight of packaging components was measured for benchmarking.

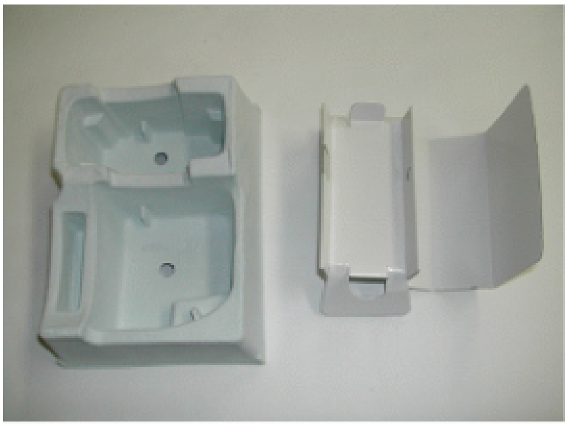

Figure 5.6 Mobile phone packaging

Table 5.5 shows the measurement results of the packaging components and its environmental improvement target. The weight of the reference product packaging was the greatest among all the products compared. This indicates that the material consumption efficiency of the reference product is the lowest among all the products compared. Since lighter packaging is desirable in minimizing the environmental impacts of packaging, the target weight was chosen as the smallest value, 167.94, realized by European 2's product. Thus, the environmental improvement target of the packaging of the reference product was to reduce its weight by 38% [(271.12-167.94)/271.12].

Table 5.5 Benchmarking results and the environmental improvement target of packaging material weight

Packaging material	Reference	Competitor 1	Competitor 2	European 1	European 2
Packaging box (g)	88.82	96.26	153.8	63.7	62.65
Inner box (g)	31.49	54.57	54.49	27.78	19.67
User's manual (g)	144.21	94.13	126.39	90.45	68.42
Etc (g)	6.6	7.39	15.91	31.16	17.2
Total	271.12	252.35	350.59	213.09	167.94
Best					V
Target	38% reduction				

Weight of a product

Weight is not only an important environmental parameter, but it is also a critical parameter for consumer's choice of a mobile phone. Table 5.6 shows the weight results of mobile phones and the target for environmental improvement. The weight of the reference product was the heaviest among all the products compared. Thus, the target for environmental improvement was set to reduce weight of a mobile phone by 24% [(66.98-50.70)/66.98].

Table 5.6 Benchmarking results and the environmental improvement target on product weight

	Reference	Competitor 1	Competitor 2	European 1	European 2
Weight (g)	66.98	50.70	53.36	59.96	62.70
Best		V			
Target	24% reduction				

Number and weight of accessory parts

Figure 5.7 shows accessory parts of a mobile phone. The number of accessories was chosen as a benchmarking parameter.

Figure 5.7 Accessory parts of a mobile phone

Table 5.7 shows measurement results of the accessory parts and its environmental improvement target. Since there are many varieties of accessory parts that come with a mobile phone, weight was chosen as the measurement metric. The weight of the reference product's accessory parts was average among all the products compared. An increased number and weight of the accessory parts indicates increased resource consumption. Since lighter weight is desirable in minimizing the environmental impacts of the accessory parts, the weight achieved by European 2's product, 143.38, was chosen as the environmental improvement target. Thus, the environmental improvement target of the accessory part of the reference product was set to reduce weight by 42% [(246.49-143.38)/246.49].

Table 5.7 Benchmarking results and the environmental improvement target of accessory parts

Accessory parts	Reference	Competitor 1	Competitor 2	European 1	European 2
Adaptor (g)	188.46	233.66	125.73	207.01	56.88
Battery (g)	51.41	60.32	55.61	22.89	27.03
Ear phone (g)	-	15	-	24.61	-
CD (g)	-	-	-	-	6.68
Cable port (g)	-	-	-	-	52.79
Leather case (g)	-	-	24.93	-	-
String (g)	6.62	6.84	11.16	-	-
Total	246.49	315.82	217.43	254.51	143.38
Best					V
Target	42% reduction				

Number of types of material

Figure 5.8 shows the disassembled parts of a mobile phone. The number of different types of materials used in a mobile phone is closely related to the recyclability of the mobile phone during its end of life cycle stage. As such, the number of different types of materials used in the mobile phone was chosen as a benchmarking parameter. As several different types of materials comprise PCBs and LCDs, both the entire PCB and entire LCD was considered as a single material, respectively.

Figure 5.8 Parts in mobile phone

Table 5.8 shows the benchmarking results of the type of materials comprising a mobile phone and its target environmental improvement. As stated below, the reference product uses the most number of materials, 18. The product with the least number of types of materials used was European 1's product, 10. Thus, the target for environmental improvement was set to reduce the number of materials used by 44% [(18-10)/18].

Table 5.8 Benchmarking results and environmental improvement target of the number of types of materials

	Reference	Competitor 1	Competitor 2	European 1	European 2
Number of types of material (EA)	18	16	16	10	11
Best				V	
Target	44% reduction				

Number of parts

The total number of parts of a mobile phone has a direct linkage to the environmental impacts of the phone, as each part has its own life cycle impact from cradle to grave. A product with similar functions, but fewer number of parts has, better the environmental performance.

Table 5.9 shows the benchmarking results for the number of parts of a mobile phone and its target environmental improvement. The reference product uses the least number of parts among the domestic products; however, the number of parts was higher than its European competitors' products. The product with the least number of parts used was European 2. Thus, the target for environmental improvement of the number of parts used was set to reducing it by 14% [(291-249)/291].

Table 5.9 Benchmarking results and environmental improvement target of the number of parts

	Reference	Competitor 1	Competitor 2	European 1	European 2
Number of parts (EA)	291	429	351	249	276
Best				V	
Target	14% reduction				

Environmental benchmarking of a mobile phone for a total of 10 parameters resulted in areas for environmental improvements. Table 5.10 summarizes the benchmarking results. Per parameter the table shows the best product in environmental performance and target values for environmental improvement. Parameters with the highest target values for the environmental improvement were the ratio of length and weight of a charge cable, and surface area of LCD, both which exceeded target values by more than 50%. Target values for other parameters ranged from 14% to 40%.

Table 5.10 Best product and target specification for each benchmarking parameter (BP)

BP \ Mobile phone	Reference	Competit-or 1	Competit-or 2	European 1	European 2	Improveme-nt target (%)
Marking of hazardous components	-	-	-	-	-	*
Surface area of PCB			V			24
Number of components on PCB				V		22
Surface area of LCD				V		52
Ratio of weight/length of cable		V		V	V	60
Weight of packaging material					V	38
Weight of a product		V				24
Number and weight of accessory parts					V	42
Number of kinds of material				V		44
Number of parts				V		14
Total number of mark	0	2	1	5	3	

* Mark the components which contain hazardous materials such as Pb, Cd, Hg, Cr^{6+}, PBB, and PBDE

5.4 Ecodesign information for mobile phone

Ecodesign information for a mobile phone came from the environmental improvement target values of each benchmarking parameter and its ecodesign guidelines. Table 5.11 lists ecodesign information for mobile phone. Note that Table 4.6 lists the relationship between environmental parameters (benchmarking parameter) and ecodesign strategies.

Table 5.11 Ecodesign information for mobile phone

Benchmarking parameter	Improvement target	Ecodesign strategy
Marking of hazardous components	*	Materials labelling including instructions for disposal
Surface area of PCB	24%	Function integration
		Standardization of components
Number of components on PCB	22%	Function integration
		Reduction of the number of materials/parts
Surface area of LCD	52%	Reduction of material input
Ratio of weight/length of cable	60%	Reduction of material input
		Use of lower energy content materials
Weight of packaging material	38%	Optimization of the weight/volume of packaging
		Reduction of material input
		Use of lower energy content materials
Weight of product	24%	Reduction of material input
		Reduction of the number of materials/parts
		Use of lower energy content materials
Number and weight of accessory parts	42%	Easy disassembly
		Reduction of material input
		Standardization of components
Number of kinds of material	44%	Reduction of the number of materials/parts
		Reduction of material input
		Use of lower energy content materials
Number of parts	14%	Reduction of material input
		Reduction of the number of materials/parts
		Use of lower energy content materials

* Mark the components which contain hazardous materials such as Pb, Cd, Hg, Cr^{6+}, PBB, and PBDE

5.5 Ecodesign ideas for mobile phone

The brainstorming technique was used to generate ecodesign tasks or ideas using the ecodesign information in Table 5.11. Rough ecodesign ideas were listed in Table 5.12. One to three rough ecodesign ideas were generated per benchmarking parameter. For instance, rough ecodesign ideas for the benchmarking parameter "surface area of PCB" were the use of a multi-functional chip, and to combine two PCBs into one.

Table 5.12 Rough ecodesign ideas of a mobile phone

Benchmarking parameter	Rough ecodesign idea
Marking of hazardous components	Indicate components containing hazardous chemicals
Surface area of PCB	Use multi-functional chip
	Make two PCBs into one
Number of components on PCB	Use multi-functional chip
	Reduce the number of components through the simplification of built-in functions
Surface area of LCD	Eliminate dual LCD function
	Make the size of LCD smaller
Ratio of weight/length of cable	Make the cable's coat thin
	Develop the plug-in type charger
	Develop the hand-worked charger
Weight of Packaging material	Integrate several manuals into one
	Use the light paper material
	Eliminate the unnecessary inner-package
Weight	Use the aluminum alloy in housing
	Minimize the thickness of housing
Number and weight of accessory parts	Sell the low frequency used part separately
	Design the battery without extra packing
Number of kinds of material	Change the housing with a single plastic
	Eliminate the ornament paint or reduce it on housing
Number of parts	Use the internal antenna

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APPENDIX A

Environmental regulations on the electrical and electronic equipment by European Union (EU)

Concerns over a sustainable society in recent years led to strict environmental regulations on industrial products, namely automotives and electrical and electronic equipment (EEE). Since the early 1990s, environmental regulation has shifted from the end of pipe concept to the front of the pipe concept. In other words, preventing pollution from the beginning by regulating the source of pollution has been the prime environmental policy tool.

One policy principle is that polluters pay. Here, the polluters apply to the manufacturer or distributor of a product, not the product-user nor the municipalities. This principle led to the development of a concept termed the extended producer responsibility. A product is envisaged as a prime source of resources consumption and environmental emissions to the air, water and land. As such, the manufacturer of the product must bear the responsibility for the wastes resulting from their products including collection, recycling, treatment and ultimate disposal.

It has also been recognized that resources consumption as well as environmental emissions from the product stem not only from the manufacturing and disposal of the product, but more importantly from the resources acquisition and processing, raw materials, and product use. In short, the entire life cycle of a product must be taken into account to reduce the environmental impact of a product. Here, environmental impact encompasses resources consumption and emissions to air, water and land. The view of the entire life cycle of a product is based on holistic thinking.

The EU is the most active region in the world, enforcing the holistic view of a product and adopting the Polluter Pays Principle based on the extended producer responsibility concept. The Integrated Product Policy (IPP) is a prime example of the EU’s policy on the environmental regulations on products.

The EU has passed environmental regulatory directives in the field of automotives and EEE that include the End of Life Vehicle (ELV) directive (CEC 2000), the Waste Electrical and Electronic Equipment directive (WEEE) (CEC 2003a), the Restrictions of the use of certain Hazardous Substances in EEE directive (RoHS) (CEC 2003b), among others. In addition, the EU is in the process of finalizing a framework directive for setting eco-design requirements for energy-using products (EuP). Of these directives, we will discuss in depth the WEEE and RoHS, and upcoming EuP directive.

One of the major differences between the WEEE and RoHS directives, and the proposed EUP directive is that the former was based on the so-called *old approach*. The *old approach* suggests that all the implementation measures of the requirements are already delineated in the directive leaving less room for misinterpretation. The *new approach*, however, does not stipulate details of implementation, rather implementation measures are later be prepared by the appropriate EU ministries that use the directive as a guide rather than a reference. Hence, the term "framework directive" that is often coined to describe the proposed EuP directive.

Since the detailed implementation measures will be the responsibility of each member state of the EU, this could create a chaotic situation for the foreign manufacturers who export products to the EU. To alienate the anticipated chaotic situation, the EU Commission requested the CEN, CENELEC, and IUTT to produce standards for the implementation measures of the EuP. This means that the European standard on eco-design will be the basis for implementing the EuP directive. Since the European standards can be challenged as technical barriers to trade, the EU standardization bodies wanted to have international standards for the eco-design implementation measures.

This appendix has several annexes that include:

- Annex I: Waste Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC)
- Annex II: The Restriction of Hazardous Substances in Electrical and Electronic Equipment (ROHS) Directive (2002/95/EC)
- Annex III: Proposal for a Directive of the European Parliament and of the Council On establishing a framework for the setting of Eco-design requirements for Energy-Using Products (EuP Directive)
- Annex IV: Legislative activities in EU centered on WEEE, RoHS and EuP directives

Annex I

Waste Electrical and Electronic Equipment (WEEE) Directive (2002/96/EC)[1]

Who does it affect?

Those involved in manufacturing, selling, distributing, recycling or treating electrical and electronic equipment (including household appliances, IT and telecommunications equipment, audiovisual equipment, lighting equipment, electrical and electronic tools, toys, leisure and sports equipment, medical devices and automatic dispensers).

Purpose

The Directive aims to:

- Reduce the waste arising from electrical and electronic equipment; and
- Improve the environmental performance of all those involved in the life cycle of electrical and electronic equipment.

Key elements

The Directive covers WEEE used by consumers and for professional purposes.

By 13 August 2005:

- Private householders will be able to return their WEEE to collection facilities free of charge; and
- Producers (manufacturers, sellers, distributors) will be responsible for financing the collection, treatment, recovery and disposal of WEEE from private households deposited at these collection facilities.
- Producers will be responsible for financing the collection, treatment, recovery and disposal of WEEE from users other than private householders from products placed on the market after 13 August 2005.
- Producers will also be responsible for financing the management of WEEE from products placed on the market before 13 August 2005. However, it may be possible for all or part of these costs to be recovered from users other than private householders.

1 http://www.environment-agency.gov.uk/netregs/legislation/380525/473094/?lang=_e

By 31 December 2006:

- Producers will be required to achieve a series of demanding recycling and recovery targets for different categories of appliance

More information of WEEE[2]

1. The primary target is domestic waste and is categorized as follows:

- Large household appliances
- Small household appliances
- IT and Telecom equipment
- Consumer equipment
- Lighting equipment
- Electrical Electronic tools
- Toys, leisure and sports equipment
- Medical services
- Monitoring & control equipment
- Automatic dispensers

Each of these is further broken down to qualify the type of equipment included and excluded. Only equipment with a voltage rating not exceeding 1000v AC and 1500v DC is included.

2. Take back requirement[3]

The WEEE Directive requires that, from the 13th August 2005 you will need to:

- Accept the take back of WEEE from householders or businesses free of charge when a like item is sold. This can be achieved in a variety of ways at according to your method of delivery, for example: -

  ✓ The consumer can bring back the old item to your point of sale if you do not offer a delivery service.

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2 http://www.getrid.uk.com/pages/weee.html

3 http://www.weeenetwork.com/Retailers.htm

- ✓ The consumer can expect you to arrange the take back the old item from their premises if you deliver the new item.
- ✓ You can arrange an alternative method of take back, through a third party agreement, but this method must not make it harder for the consumer to return the product. For example, the consumer can post (at your expense) the old item to a third party because you have given them a stamped addressed envelope (this is suitable for small items such a mobile phone).

- Let consumers know about the take-back services you offer, or alternative schemes.
- Ensure that all separately collected WEEE enters a logistical chain whereby the end result is reuse or recycling. Separately collected WEEE cannot be disposed of in a landfill site or incinerated.

3. Recovery target

Minimum end-of-life reuse, recycling and recovery targets set by the WEEE Directive are shown as follows:

Product category*	Rate of reuse/recycling by average appliance weight (%)	Rate of recovery** by average appliance weight (%)
Large household appliances (e.g. Fridges, washing machines, electric ovens etc)	75	80
Small household appliances (e.g. Vacuum cleaners, toasters, etc)	50	70
IT and telecommunication equipment (e.g. Computer, photocopiers, etc)	65	75
Consumer equipment (e.g. Televisions, video recorders, etc)	65	75
Lighting equipment (e.g. Fluorescent lamps, discharge lamps etc)	80	N/A
Electrical and electronic tools (e.g. Drills, sewing machines etc)	50	70
Toys, leisure and sports equipment (e.g. Video games, train set etc)	50	70
Medical equipment system (e.g. Radiotherapy equipment etc)	No target has been set	No target has been set
Monitoring and control equipment (e.g. Thermostats, control panel etc)	50	70
Automatic dispensers (e.g. Drinks machines etc)	75	80

*See the WEEE Directive at wwww.dti.gov.uk/sustainability for further details

**Includes energy recovery in a power plant, in addition to reuse and recycling

Annex II

The Restriction of Hazardous Substances in Electrical and Electronic Equipment (ROHS) Directive (2002/95/EC)[4]

Who does it affect?

Manufacturers, sellers, distributors and recyclers of electrical and electronic equipment containing lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls or polybrominated diphenyl ethers.

Purpose

The Directive aims to:

- Protect human health and the environment by restricting the use of certain hazardous substances in new equipment;
- Complement the WEEE Directive.

Key elements

- From 1 July 2006 new electrical and electronic equipment will not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls or polybrominated diphenyl ethers.
- Certain applications are exempt from the requirements of the Directive including mercury in certain types of fluorescent lamps, lead in the glass of cathode ray tubes, electronic components and fluorescent tubes, lead in electronic ceramic parts and hexavalent chromium as an anti-corrosion of the carbon steel cooling system in absorption refrigerators. The exemptions will be reviewed every four years.
- Before 13 February 2005 the European Commission will review the terms of the Directive to take into account any new scientific evidence.

Timescale

The Directive is to be brought into force in the EU state by 13 August 2004.

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4 http://www.environment-agency.gov.uk/netregs/legislation/380525/477158/?version=1&lang=_e

Annex III

Proposal for a Directive of the European Parliament and of the Council On establishing a framework for the setting of Eco-design requirements for Energy-Using Products (EuP Directive)[5]

The EuP (Energy using Products) Directive is a draft European document that combines the previous draft EEE and EER Directives (impact on the environment of Electrical and Electronic Equipment and Energy Efficiency Requirements respectively).

The latest full text of the Directive can be found with the link to the right (http://europa.eu.int/eur-lex/en/com/pdf/2003/com2003_0453en01.pdf). It is expected to become law in member states by 31st of December 2005, and manufacturers will be obligated to comply from the 1st of July 2006.

Objective

The aim of this initiative is to provide eco-design requirements for energy using products.

- Ensure the free movement of energy-using products within the EU.
- Improve the overall environmental performance of these products and thereby protect the environment.
- Contribute to the security of energy supply and enhance the competitiveness of the EU economy.
- Reserve the interests of both industry and consumers.

Scope

Whilst the EuP Directive can, in principle, be applied to any product that uses energy to perform its task, it is likely to only cover those that use electricity, solid, liquid and gaseous fuels.

An important difference from the WEEE regulations is that components part manufacturers, and not just the whole product manufacturers, will be affected. Components that are both sold to an end user and that can be assessed independently

5 http://www.weeenetwork.com/EuP.htm

for environmental performance will fall under the obligation.

'For example, although a part may be sold directly to a customer e.g. an individual resistor or capacitor, major environmental aspects may depend upon the way that this part is used in the final product. In this case an independent analysis of its environmental performance is neither possible nor meaningful…'

However, component manufacturers will be obliged to provide basic information concerning materials and energy consumption.

All products that fall under the WEEE Directive will also be subject to the future EuP Directive, and as with WEEE, vehicles are exempt.

Requirements

Manufacturers will have to look at the entire life cycle of their product, as well as making an ecological assessment. This includes an analysis taking into consideration:

- Raw materials used
- Acquisition
- Manufacturing
- Packaging, transport and distribution
- Installation and maintenance
- Use
- End of Life

The assessment will include consumption of materials and energy, emissions to the environment, expected waste and ways of recycling and reuse. There are existing schemes such as the 'Eco label' that will meet many of the requirements and the same information can be used to show compliance.

Compliance

There are two routes to compliance, either through 'internal design control' where information through testing is gathered and formed into profiles, or through the implementation of an 'environmental management system' where a control loop of planning procedures are documented.

Future

The exact requirements on certain products, timing (there are expected to be some implementation stages) and scope are still very much under discussion, yet this new law will hopefully be shaped up rapidly as it seems that the EU and the UK are keen to learn from complaints made about the introduction of WEEE and RoHS.

More information of EuP[6]

The European Commission proposes a Directive on the eco-design of energy-using products, such as electrical and electronic devices or heating equipment. Coherent EU-wide rules for eco-design will ensure that disparities among national regulations do not become obstacles to intra-EU trade. The proposal does not introduce directly binding requirements for specific products, but does define conditions and criteria for setting, through subsequent implementing measures, requirements regarding environmentally relevant product characteristics (such as energy consumption) and allows them to be improved quickly and efficiently. Products that fulfill the requirements will benefit both businesses and consumers, by facilitating free movement of goods across the EU and by enhancing product quality and environmental protection. The proposal constitutes a breakthrough in EU product policy and introduces many innovative elements together with concrete application of the principles of the "better regulation" package.

By encouraging manufacturers to design products with the environmental impacts in mind throughout their entire life cycle, the Commission implements an integrated product policy and accelerates the move towards improving the environmental performance of energy-using products.

After adoption of the Directive by the Council and the European Parliament, the Commission, assisted by a Committee, will be able to enact implementing measures on specific products and environmental aspects (such as energy consumption, waste generation, water consumption, extension of lifetime) after impact assessment and broad consultation of interested parties.

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6 http://www.weeenetwork.com/EuP.htm

There will not be obligations for all energy-using products, but only for those meeting criteria such as important environmental impact and volume of trade in the internal market and clear potential for improvement, for example where market forces fail to make progress in the absence of a legal requirement.

This policy initiative is expected to increase the effectiveness and synergies of other EU legislative acts and initiatives concerning environmental aspects of products. Examples of related measures are the Directives regulating the management of waste from electrical and electronic equipment (WEEE) and the use of certain hazardous substances used in this equipment (RoHS) as well as Directives related to the energy efficiency of appliances such as the Energy labelling Directive. Existing Directives on minimum energy efficiency requirements shall be considered as implementing this Directive for the products that they cover with regard to energy efficiency during use.

Products that have been awarded the Eco-label will be considered as compliant with the implementing measures in so far as the Ecolabel meets the requirements of the implementing measure. Although the EMAS registration on its own does not grant presumption of compliance to the products manufactured by the enterprise, enterprises that have an EMAS registration, which includes product design, may use directly their environmental management system for demonstrating that their product complies with the applicable implementing measure.

- **What is eco-design?**

The environmental impacts of energy-using products take various forms, such as energy consumption and related negative contribution to climate change, consumption of materials and natural resources, waste generation and release of hazardous substances.

Eco-design, which means the integration of environmental considerations at the design phase, is arguably the best way to improve the environmental performance of products.

The creation of a coherent framework for environmental product policy will avoid the adoption of uncoordinated measures that could lead to an overall negative result; for example eliminating a toxic substance from a product, such as mercury from lamps, might lead to increased energy consumption, which on balance would have a negative impact on the environment.

A Community framework will also ensure that no divergent national or regional measures that could hinder the free movement of products and reduce the competitiveness of businesses are taken.

Businesses and consumers will benefit greatly not only from better products and an improved environment, but also economically, because of a more rational use of resources. Easier access to an enlarged EU single market will help enhance competitiveness in the global market place, where environmental concerns are becoming increasingly important. The environment will also gain from this Commission initiative, which tackles all environmental considerations holistically.

The proposal shows the determination of the Commission to integrate environmental aspects in enterprise policies. Its structure (clear framework given by Council and Parliament, technical measures adopted by the Commission) and scope (environmental aspects of products with a view to safeguarding the internal market) present many new elements. Mechanisms for rapid, efficient and participatory decision-making are proposed, which at the same time leave sufficient room for innovation and initiative to product manufacturers. Widespread application of environmentally friendly processes and products is among the goals of both the 6th Community Environment Action Programme and of the Commission Communication on Industrial Policy in an Enlarged Europe.

The introduction of eco-design measures that include requirements for improved energy efficiency of products is also an important and long-lasting contribution to combating climate change securing energy supply and achieving sustainable development.

Annex IV

Legislative activities in EU centered on WEEE, RoHS and EuP directives

Electrical and electronic equipment has the authorities' attention, primarily because of the rising amounts of waste and the connected disposal problems. This is the reason why since the beginning of the nineties there has been an ongoing work on legislation in this field, starting in Germany, Denmark, The Netherlands, Sweden and Norway, as well as on the EU-scale.

The regulations are primarily concerned with:

- Establishing collection systems and securing correct handling of waste, which means recycling and regaining of resources
- Safe separation and disposal of environmental hazardous parts
- Certain hazardous substances, which will either be banned or restricted in use

The regulations also introduce a producer responsibility for the disposal, and demands information from the producer to the recycler about e.g. the content of environmentally hazardous parts and possibilities for recycling.

Key points of the three EU-directives, WEEE, RoHS and EuP, are shown as follow:

Directive	Main Content	Status
WEEE directive	● Specifies collection requirements and targets in the member states ● Specifies recycling targets ● Introduces producer responsibility for the disposal costs ● EE-equipment shall be marked, telling the consumer not to dispose it with normal waste stream ● Producer must provide information to recyclers	Final Directive to be implemented in national legislation by August 2004.
RoHS directive	● Introduces ban on the use of Lead, Mercury, Cadmium, hexavalent Chromium, Beryllium ● Introduces ban on certain brominated flame retardants (PBB & PBDE)	Final Directive to be implemented in national legislation by August 2004.
EuP directive	● The proposal does not introduce directly binding requirements for specific products, but does define conditions and criteria for setting, through subsequent implementing measures, requirements regarding environmentally relevant product characteristics (such as energy consumption) and allows them to be improved quickly and efficiently. ● After adoption of the Directive by the Council and the European Parliament, the Commission, assisted by a Committee, will be able to enact implementing measures on specific products and environmental aspects (such as energy consumption, waste generation, water consumption, extension of lifetime) after impact assessment and broad consultation of interested parties.	Proposal from the EU Commission Follow the development from the EU Commissions web page

APPENDIX B

Ecodesign strategies

A total of 25 different ecodesign strategies were defined in this book for the implementation of ecodesign. Rationale behind each ecodesign strategy is delineated below.

1. Indication of resource/energy consumption along the use stage

As the consumption of materials and energy are related directly to the operating and maintenance costs of a product that a consumer purchases, consumers pay attention to the consumption of materials and energy during the product use stage. If relevant information is provided to the consumers, e.g., electricity consumption during product use, the consumers may change their consumption behavior and reduce consumption. For example, in the case where washing machines provide relevant consumer information, such as optimum washing time and specific efficiencies based on laundry type, consumer consumption behavior will generally reflect this information.

2. Material labeling including instructions for disposal

Products or components, once disposed of after use, must be recycled if they are not reused. Hence, it is essential to mark the material type of the product on the product and components. In particular, packaging must also show instructions on the appropriate disposal method in addition to the material identification mark.

3. Easy disassembly

Disassembly is prerequisite to most recycling operations. Labor costs are one of the most significant costs involved in the disassembly. Thus, the minimization of disassembly time is an essential ingredient for reducing the disassembly cost. This leads to a product designed for easy disassembly. Most of the time, easy disassembly means easy assembly; hence, designing a product for easy disassembly also reduces the cost of product assembly.

In general, products consist of various parts and components connected by various types of joints. Typical types of joints include snap fits, spring clips, and screws, among others. Sometimes it is necessary to use materials that are not possible to recycle. Thus, joints must also be chosen for easy disassembly (Wimmer 2002).

4. Inclusion of disposal instructions for users

Generally speaking, consumers do not like to spend the time nor effort in disposal of a wasted product, as such an easy to understand and easy to implement disposal instruction set for the consumer is necessary. In addition, text encouraging consumers to practice safe disposal methodologies may increase chances for proper disposal of a wasted product. Below is an example of Apple Computer Company's label for safe disposal of a dead battery.[1]

To dispose of a dead battery:

- Place it in a packaging that came with your replacement battery.
- Return the dead battery to your authorized Apple service provider for proper disposal.

5. Easy maintenance and repair

Ease of repair of a product by consumers is essential for extending lifetime of a product. It is thus necessary to provide the product structure for easy disassembly in case of where repair needed. A product should also be designed where standardized tools can be used to repair the product. In addition, a uniform service period of a product and parts should be ensured during its design process (Wimmer 2002).

6. Easy upgradeability

A product designed for easy upgradeability leads to the extension of its lifetime. This is particularly true for today's products where the lifetime of a product is getting shorter and shorter due to the influx of new products with new functions. In fact, in most cases, the technical lifetime of a product is a lot longer than useful lifetime of a product.

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[1] Apple, 2002. Macintosh portable battery care and disposal instructions, http://download.info.apple.com/Apple_Support_Area/Misc/Inserts/073-0304.pdf

Most products, in particular electronic products, can be upgraded by replacing outdated components with newer ones. Thus, a modular design that allows the substitution of an old component for an upgraded one should be implemented. With an upgradeability feature the useful lifetime of a product can be extended significantly.

7. Environmentally friendly surface design

A product with a difficult to clean surface tends to shorten its useful lifetime. Consumers tend to discard products with aesthetic problems, even though there is no impairment in its function. Thus, product designer should pay particular attention to the design of the appearance of the product, in particular surface design. The surface should be easy to clean and no environmental problems should incur during the cleaning process.

Corrosion shortens the lifetime of a product. It also makes recycling and reuse difficult. To prevent corrosion from the surface of the product, appropriate anti-corrosion agents should be applied or the use of anti-corrosive materials should be considered in the product design process. The anti-corrosion agents should not pose any threat on the environment. In addition, the use of anti-corrosion agents should not deter the recycling of the materials. (Wimmer 2002).

8. Function integration

Integrating multi-functions into a single product can lead to savings in resources. In turn, this results in less emission of pollutants into the environment. Caution must be exercised not to design a product with inferior performance due to functional integration.

9. Standardization of components

Simplification of components and parts of a product after disassembly is necessary for an efficient recycling operation. This requires the use of standardized components for a product. Parts, components, and assemblies with similar functions should employ similar structure, size and materials, if possible. Standardizing components and parts will also reduce the number of tools for disassembly and enhance the reuse possibility of parts and components. Furthermore, disassembly costs will also decrease (Wimmer 2002).

10. Avoidance/reduction of toxic materials

The use of toxic substances in a product should be banned for the sake of human and ecosystem health, for even trace amount of it could exert harmful impacts on both the environment and humans. Coloring agents, stabilizers, and other toxic additives for the manufacturing plastics should also be banned or minimized at the least.

Recent EU directive, RoHS[2] prohibits the use of six hazardous substances in the electronic products. OEM (Original Equipment Manufacturing) companies demand material information in the form of Material Safety Data Sheet (MSDS) from their suppliers.

When the use of toxic substances is unavoidable due to technical reasons, then information on the use of those toxic substances must be disclosed for efficient recycling and disposal operations. The same applies to the design of packaging. Pertinent information regarding the use of toxic substances in packaging, if any, must be disclosed.

11. Minimization of process materials in use stage

Process materials are materials used for the operation of a product during its use stage. These not only include materials such as water or energy, but also other consumables such as detergents, coffee filters, and batteries, or toner cartridges. The minimization of the use of process materials should be ensured such that product design must consider options to minimize process materials for the operation of the product during its use stage. Possible options may include the use of rechargeable batteries instead of alkaline disposable batteries, and efficient design of a product that reduces the water and detergent consumptions, among others.

A well-known example may be the case of the Dyson vacuum cleaner. This vacuum cleaner eliminates the use of process materials completely and at the same time improves product performance. Typical vacuum cleaners require 60 dust collection bags during the entire lifetime of a product. However, in the case of the Dyson vacuum cleaner, no dust collection bag was used. Instead, the vacuum cleaner design adopts

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[2] CEC (Commission of the European Community) (2003b), Directive 2002/95/EC of the European parliament and of the council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment

the cyclone system principle. This innovative product idea not only eliminates the dust collection bag, but also improves the vacuuming efficiency with the accompanying reduction in electricity consumption.[3]

12. Reduction of material input

The reduction of material inputs into the manufacturing of a product and packaging should take into account safety and stability of both the product and packaging. Inherent functions of both the product and packaging cannot be realized without due consideration to these factors. Thus, material inputs must be reduced to a point where optimum strength of each part is maintained. The use of reinforcement ribs, bosses, and gussets are possible options for this purpose.[4] This strategy also applies to ancillary materials inputs.

Table B.1 prepared by World Reserves Life Index (WRLI) shows available resources for human use. The available resources represent resources that are extractable economically and termed the "world resource lifetime index[5]." It is clear from this table that scare resources must be replaced by non scare resources as much as possible.

13. Reduction of the number of materials/parts

If at all possible, the use of a single type of material should be sought over mixed types of materials. However, the use of a single type of material may pose a threat to the strength of a product or may not realize the desirable attributes of a product manufacturing.

Reducing the number of parts and the use of similar or common parts applicable to many different types of products make assembly and disassembly simple and repair easy (Wimmer 2002).

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[3] Dyson (2002), http://www.dyson.co.uk

[4] APC(American Plastics Council) (2002), A design guide for information and technology equipment, http://www.plasticsresource.com/reading_room/ reports/report_enviro_design.html

[5] IPU(The Institute for Product Development), DTC(Danish Toxicology Centre), GN-Teknik (2002), A Designer's Guide to Eco-conscious Design of EEE, Denmark, http://www.gnteknik.dk/

14. Reuse of refurbished parts and components

Reuse of parts allows closed loop recycling possible. This is much better environmentally compared to the virgin manufacturing of parts and components. Refurbished parts and components have proven defect free during their service periods. Sometimes reliability of refurbished parts and components are better than that of the virgin parts. Thus, there is no need to be concerned over the quality of the refurbished parts and components (Wimmer 2002).

15. Use of lower energy content materials

There are energy intensive materials during resource extraction and subsequent processing to produce raw materials. Typical example is aluminum. The energy input to produce virgin aluminum is 184 MJ/kg, while the energy input to produce recycled aluminum is 18.5 MJ/kg. Thus, a product design should accommodate the use of recycled aluminum. If there is less opportunity for recycling, the use of materials with high energy intensity should be deterred in the first place. Table B.2 lists the energy consumption of materials in its resource extraction and processing. In the case of plastics shown in this table, the energy value includes energy recovered during the combustion of the plastics in the incinerator.

Table B.1 World reserves life index (IPU et al 2002)

Resource	World reserves life index (years)	Known global reserves per person (kg/person)
Oil	43	25,600
Coal	170	98,570
Lignite	390	98,130
Natural gas(m^3/prs)	60	23,440
Aluminum	200	660
Iron	120	12,200
Lead	20	13
Copper	36	60
Manganese	86	150
Nickel	50	9
Tin	27	1.1
Zinc	20	30
Silver	-	0.15
Gold	-	0.011
Palladium	-	0.008
Tantalum	-	0.047
Antimony	-	1
Cobalt	-	1
Molybdenum	-	4
Cadmium	-	0.23
Lanthanium	-	3.2
Cerium	-	5.9
Beryllium	-	0.038
Mercury	-	0.11
Platinum	-	0.008

Table B.2 Primary energy input for production/combustion of materials (IPU et al 2002)

Materials	Total Energy input [MJ/kg]	Combustion value for Material [MJ/kg]
Aluminium, Al	170	0
Glass	10	0
Copper, Cu	90	0
Magnesium, Mg	150	0
Brass	80	0
Nickel, Ni	190	0
Paper/cardboard	40	20
Plastic, ABS	95	40
Plastic, EPS-expanded polystyrene	79	48
Plastic, PA	140	30
Plastic, PC	115	30
Plastic, PE	75	40
Plastic, PET	80	30
Plastic, PMMA	110	40
Plastic, POM, polyoxymethylene	84	45
Plastic, PP	80	40
Plastic, PS	90	40
Plastic, PUR	110	30
Plastic, PVC	65	20
Plastic, SAN, Styrene acryl nitrile	90	40
Synthetic rubber, polybutadiene	35	46
Stainless steel	46	0
Silicon, Si	220	0
Cast iron	30	0
Steel	40	0
Wood	0.2	18
Zinc, Zn	70	0

16. Use of recyclable materials

Product designer should consider factors needed for use of recyclable materials in a new product. Use of recyclable materials for the manufacturing of the same product is termed closed loop recycling. There are three factors to consider in the case of closed loop recycling. They are: i) recyclable materials must be fed into the manufacturing process of new products, Ii) no significant quality degradation is allowed for the recycled materials, iii) the collection system of the discarded products must be in place (Wimmer 2002).

Relationships between materials for recycling and use of those materials in the manufacturing of new products are summed up in Tables B.3, B.4 and B.5[6]. This information can be useful for a product design aimed at recycling.

Table B.3 Compatibility of metals (Brezet and Hemel 1997)

Metal (Processed by way of melting processes)	Knock-out elements (Decreases value of the fraction to zero)	Penalty elements (Seriously decrease the value of fraction)
Copper (Cu)	Hg, Be, PCB (polychlorobenzene)	As, Sb, Ni, Bi, Al
Aluminium (Al)	Cu, Fe, polymers	Si
Iron (Fe)	Cu	Sn, Zn

[6] Brezet, H. and Hemel, C. V. (1997), ECODESIGN-A PROMISING APPROACH to sustainable production and consumption, UNEP. http://www.unepie.org/home.html

Table B.4 Compatibility of plastics (Brezet and Hemel 1997)

	PS	SAN	ABS	PA	PC	PMMA	PVC	PP	PE, LD/HD	PET	Thermosets
PS	+	-	-	-	-	0	-	-	-	-	-
SAN	-	+	+	-	+	+	+	-	-	-	-
ABS	-	+	+	-	+	+	0	-	-	-	-
PA	-	-	-	+	-	-	-	-	-	-	-
PC	-	+	+	-	+	+	-	-	-	+	-
PMMA	0	+	+	-	+	+	+	-	-	-	-
PVC	-	+	0	-	-	+	+	-	-	-	-
PP	-	-	-	-	-	-	-	+	-	-	-
PE,LD/HD	-	-	-	-	-	-	-	-	+	-	-
PET	-	-	-	-	+	-	-	-	-	+	-
Thermosets	-	-	-	-	-	-	-	-	-	-	-/0/+

+ : good, 0 : moderate, - : poor/nil

Table B.5 Compatibility of glass and ceramics (Brezet and Hemel 1997)

	Bottle glass	Window glass	Drinking glass	Drinking glass(c)	TV (screen)	TV (cone)	TV (neck)	LCD (screen)	Ceramics
Bottle glass	+	-	-	-	-	-	-	-	-
Window glass	+	+	+	-	-	-	-	-	-
Drinking glass	+	0	+	-	-	-	-	-	-
Drinking glass(c)		-	-	+	-	0	0	-	-
TV (screen)	0	0	-	-	+	0	-	-	-
TV (cone)	-	-	-	0	-	+	+	-	-
TV (neck)	-	-	-	0	-	-	+	-	-
LCD (screen)	0	0	-	-	0	-	-	+	-
Ceramics	-	-	-	-	-	-	-	-	-/0

+ : good, 0 : moderate, - : poor/nil

17. Use of recycled materials

Use of recycled material significantly reduces the consumption of resources required for the manufacturing of products. At the same time, wastes from the manufacturing process can also be reduced. This is translated into savings in materials going into the product system.

18. Use of renewable materials

Every attempt should be made not to use or minimize the use of non-renewable resources in the manufacturing of products. This is particularly true if the resources of concern are scarce ones. Thus, product designer should design a product using renewable resources as much as possible. See Table B.1 for lifetime of resources.

19. Minimization of waste/environmental emissions

Process wastes are envisaged as ineffective use of materials during the manufacturing process of a product. Process wastes are in fact the loss of money, for they come from raw and ancillary materials going into the manufacturing process. The elimination of the process wastes through product design change is the utmost means in reducing disposal costs of the process wastes.

Process emissions can also be burdensome to the environment. Using cleaner energy, for instance, can lead to the minimization of process emissions into the environment. Table B.6 (IPCC: Intergovernmental Panel on Climate Change)[7] shows the carbon emission factor for different types of fuel. Based on the information in this table, product designer can choose energy type for product during its manufacturing and use stages.

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[7] Houghton, J., Meira, F., Lim, B., Treanton, K., Mamaty, I., Bonduki, Y., Griggs, D., Callander, B., 1997, Greenhouse Gas Inventory Reference Manual- Revised 1996 IPCC guidelines for national greenhouse gas inventories, London, UK:IPCC, OECD, IEA

Table B.6 IPCC carbon emission factor (Houghton 1997)

			Carbon emission factor		
			Kg C/GJ	(Ton C/toe)	(TJ/10^3TON)
Liquid fossil	Primary fuel	Crude oil	20.00	0.829	-
		N. Gas Liquids	17.20	0.630	-
	Secondary fuel	Gasoline	18.90	0.783	44.80
		Other Kerosene	19.60	0.812	44.75
		Jet Kerosene	19.50	0.808	-
		Gas/Diesel Oil	20.20	0.837	43.33
		Residual Fuel Oil	21.10	0.875	40.19
		LPG	17.20	0.713	47.31
		Naphtha	(20.00)	0.829	45.01
		Bitumen	22.00	0.912	40.19
		Lubricants	(20.00)	0.829	40.19
		Petroleum Coke	27.50	1.140	31.0
		Refinery Feedstock	(20.00)	0.829	44.80
Solid fossil	Primary fuel	Anthracite	26.80	1.100	
		Coking Coal	25.80	1.059	
		Other Bit. Coal	25.80	1.059	
		Lignite	27.60	1.132	
		Peat	28.90	1.186	
	Secondary fuel	BKB & Patent Fuel	(25.80)	1.059	
		Coke Oven/Gas Coke	29.50	1.210	
		Coke Oven Gas	13.0		
		Blast Furnace Gas	66.0		
Gaseous fossil		LNG (dry)	15.30	0.637	
Total biomass		Solid biomass	29.90	1.252	
		Liquid biomass	(20.00)	0.837	
		Gas biomass	(30.60)	1.281	

20. Waste recycling/reuse

Wastes are generated in any manufacturing processes. Proper treatment of the wastes is a must. However, the disposal cost, in particular landfilling cost, increases year by year, such that landfills will not be a viable option in the near future. Thus, new options must be developed to reuse or recycle waste for the manufacturing of other products, the same type of product or different type of product.

21. Optimization of the weight/volume of packaging

Packaging should be designed to its minimum in size (volume) and weight while meeting the requirements of safety, health, and consumer's needs. In addition, the packaging must be designed for reuse and recycling. Volume coefficient of packaging (VCP)[8] is a useful indicator evaluating the degree of optimization of the package's volume and weight. It is a ratio between the volume of the package and the weight of the product (content). Reduction in the value of the VCP can be considered optimization of packaging and its content or product.

22. Use of reusable packaging

Sturdy packaging such as Kraft paper boxes can reduce the consumption of raw materials, for it can be reused. Thus, designing reusable and sturdy packaging is necessary to reducing the environmental impacts caused by packaging.

23. Minimization of energy consumption in use stage

Electronics and automotives use a significant amount of energy during its use stage. In general, the use stage is the most dominant life cycle stage for these types of products. Thus, the minimization of energy consumption in the use stage is a mandatory feature of these energy intensive products.

24. Minimization of energy consumption in production stage

Energy consumption during the manufacturing of a product depends on the manufacturing technology used by the manufacturer. Thus, product designers should

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[8] Boeglin, N., 1999, Product design and environment - 90 examples of eco-design, ADEME Editions, Paris

select energy saving technology for the manufacturing process.

25. Use of renewable energy resources

It is essential for a product developer to design a product that uses renewable energy in its manufacturing and use. Solar energy, biomass energy, wind energy, thermal energy and waterpower are typical examples of renewable energy sources.

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