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DEPARTMENT OF MANAGEMENT, ECONOMICS AND INDUSTRIAL ENGINEERING

Integration of Sustainability into New Product Design

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ABSTRACT

This dissertation examines the integration of sustainability into product design, mainly focusing on the environmental aspects.

Product development is one of the most critical aspects for companies in reaching their sustainability objectives. However, the support needed for making sustainability related decisions are not systematically integrated in companies today. So, it is a necessity to create generic methods and tools that helps the integration of sustainability aspects in decision making and product development.

The main objective of this thesis is to understand how and what companies are doing currently to integrate sustainability into their products and product design processes. We intend to identify the gap between the literature and the practice in order to help researchers to develop a modified or a new method of integrating sustainability criterions into the product development processes that fill the existing gap.

To pursue this aim, an explorative research has been implemented through the use of an on-line survey proposed to over 200 companies, of which only 10 companies responded. In order to increase the relevance of the entire work, further 3 case studies including face to face interviews and analyzing the internal documents had been done.

The survey and cases revealed that sustainability is not well integrated into product design yet and is not the primary concern for R&D studies of companies. Ecodesign improvement options only stand a chance, if they are supported by some stimuli related to economical aspects apart from just environmental benefits. So, it is not likely that a company will make a choice that is not primarily economically driven. In addition, companies mostly think ecodesign as achieving long term objectives. In reality, most of the decisions and interest depend on either costs or long term plans as image improvement and entering to new markets.

The output of this paper will help those who want to pursue a research in the area, to include sustainability dimension in product development course, and for those companies who are interested to understand and adopt tools and methods that is suitable for their company.

Keywords: Sustainable development, Sustainable product design, Ecodesign, Product development

1. INTRODUCTION

Sustainability has three main pillars: Environmental, economic and social aspects. Within the environmental aspect, the new product should simply not produce and emit substances which possess high impact towards global warming, biodiversity and toxicity. While for the economic aspect, the design as much as possible must minimize the cost by reducing the use of material, energy and resources. In addition, the aspect of human health must also be considered during the design stage. This is done by eliminating the use of hazardous material, reducing nuisance by lowering the noise level and particulate matter during the manufacture of the product.

In the last couple of decades, significant research work has been carried out in order to investigate different ways of supporting engineers in the development of more sustainable products. However, most of the efforts and studies are mainly directed towards the environmental aspect of sustainability as the industrial world has changed its approach to the environment. The importance of the environmental sustainability of industrial products and processes derives not only from the ever stricter-becoming environmental legislations issued in most of the developed countries, but also from the higher awareness of customers concerning environmental problems. The competitiveness of putting on the market more sustainable products, in particular, is becoming a key factor in recent years.

Growing environmental concerns, coupled with public pressure and stricter regulations, are fundamentally impacting the way companies design and launch new products across the world (Choi et al., 2008). Therefore, companies are confronted with the responsibility of producing products in an environmentally friendly manner. This requires the next generation of engineers to be trained in the context of sustainability, along with a global perspective, in order to solve problems of sustainability on multiple scales (Miheclic et al., 2008).

The issue of environmental sustainability is extraordinary in both magnitude and complexity, and as such is one of the greatest challenges faced by modern society (NAE, 2008). Moreover, as a result of population growth and the improvement in quality of life (Chertow, 2001), more and more products will be used to provide services or consumed by people directly, further complicating the quest for environmental sustainability.

While many different enterprises and systems are involved from concept to end-of-life and recycling of products, it also requires a shared responsibility to implement and realize sustainability throughout the life cycle. Ultimately, designers and product engineering management must understand possible designs for environment strategies. Innovation is an integral part that must balance business with other constraints to find the best strategy for product lines. Information requirements of engineering designers for eco-design have to be served in a manner such that both manufacturing and life-cycle use of the product are eco-friendly. Figure 1 illustrates the necessary considerations during design to achieve sustainable product development. Also, the integration of downstream issues into design is a complex task. The ambiguity attributed to a concept during the early design phase creates grand challenges for the development of appropriate, accurate metrics related to sustainability (Ramani et al., 2010).

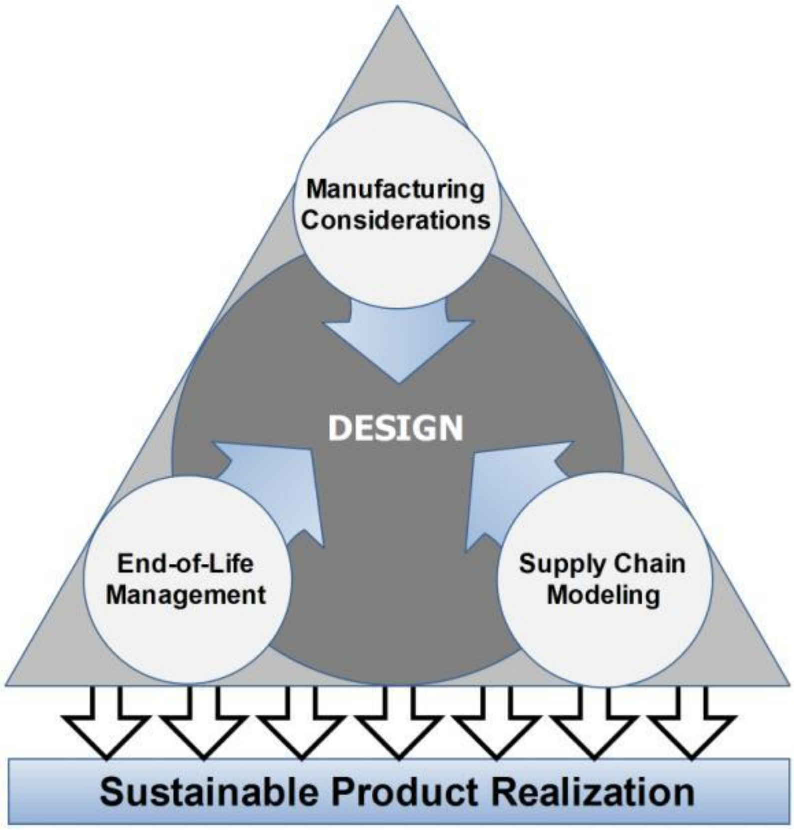


Figure 1: Design decisions' effect on the stages of a product's life (Ramani et al., 2010)

Recently, countries and society pay more and more attention to improve environment and one of the objectives to gain importance for the companies is to create environmentally friendly products. One of the most striking areas where companies now have to be concerned is the environment. The concern regarding environmental impact stems from the fact that, whether we want it or not, all our products affect in some way our environment during their life-span. As a result, environment problems get more and more attentions in government, consumers and industries.

It is clear, then, that beside the traditional activities of prevention and control, producers have to deal with more and more complex issues, which are related to a longer cause-effect chain. From designers' point of view, the development of more environmentally-friendly products brings them to take into consideration environmental aspects in concurrence with traditional technical and economical aspects since the beginning of design activities. The requisites an industrial product has to be in compliance with, have become more numerous and stricter than in the past, involving also social aspects, i.e. the impact that industrial products have on the society in general, considering for example their performances from the safety and the environmental point of view (Fargnoli, 2005).

Certainly, this consciousness recently acquired regarding environmental problems and the knowledge about tools aimed to reduce them, is increasing in the industrial world. There is an awareness of need for environmental friendly tools to be used in a systematic way, in a well defined design procedure, in combination with design strategies. The development of more environmentally-friendly products leads designers to take into consideration environmental aspects in concurrence with traditional technical and economical aspects since the beginning of design activities. Such an evolution requires the use of specific tools for the development and management of design activities: the most powerful tool at designers' disposal upon facing these problems is certainly represented by the Ecodesign approach. Ecodesign certainly represents the most effective design approach for the achievement of such goals. A large number of tools proposed in the recent years are an indicator of the great attention paid to such problems. However, the use of such tools by designers is still partial or not well organized.

Product development is one of the most critical aspects for companies in reaching their sustainability objectives as almost all the products consumed by people are outputs of the product development process. In particular, early design decisions can have a very significant impact on sustainability. These decisions not only relate to material and manufacturing choices, but have a far-reaching effect on the product‘s entire lifecycle, including transportation, distribution, and end-of-life logistics. However, key challenges have to be overcome to enable eco-design methods to be applicable in early design stages. However, the support needed for making sustainability related decisions are not systematically integrated in companies today, especially in early design that has the most crucial effects on sustainability of the product. So, it is a necessity to create generic methods and tools that helps the integration of sustainability aspects in decision making and product development. In order to do this, good knowledge of the regarding tools and of the studies in the literature has to be pursued. Afterwards, it is just a matter of wisdom to choose the appropriate tools and the right context of application.

Such an evolution requires the use of specific tools for the development and management of design activities: the most powerful tool at designers' disposal upon facing these problems is certainly represented by the Ecodesign (or Design for Environment) approach (McAloone, 2000). In this field, a large number of methods and techniques are available nowadays, both considering the outputs of academic research works, as well as efforts made by international organizations.

However, there is little support available for designers on how to implement these different tools toward an effective and efficient DfE. In other words, the supply of current DfE methods and tools relatively lacks a systematic approach as a whole. Above all, the most significant difficulty is the lack of coordination of design activities, i.e. how to put into practice the indications provided by the Ecodesign tools and guidelines (Bygget and Hochschorner, 2006). For these reasons, a study on the design process and its optimization in order to meet environmental requirements was carried out, with the final aim of finding a way to reduce the gap between theory and practice (Lofthouse, 2006).

Evolution of the concept of environmental sustainability in the industrial world has brought to light the importance assigned to the first stages of the product development, i.e. the early-phase design activities. It is of common knowledge that decisions made in these phases allow the products' optimization from the performances point of view, as well as more competitiveness on the market, drastically reducing the costs related to subsequent modifications and corrections of the product during the manufacturing phases or even after its introduction in the market.

Ecodesign certainly represents the most effective design approach for the achievement of such goals. A large number of tools proposed in the recent years is an indicator of the great attention paid to such problems. However, the use of such tools by designers is still partial or not well organized, particularly in SMEs (small and medium sized enterprises). The research work carried out is an attempt to the solution of these difficulties. This paper proposes a design procedure, consisting in the integration of several design tools in a framework of a general nature aimed at reducing the gap between theory and practice.

2. RESEARCH PURPOSE

2.1. Introduction

This chapter aims to provide a brief but precise description of the research purpose by introducing the research context, research questions, the research hypothesizes and objectives. It also explains the basic rationale and link between those and the literature review.

2.2. Research Context

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.

In recent years, considerable innovation has gone into product design and management. The aim of innovation is to reduce time taken and resources used in design, production, distribution, and disposal of products with elevated and diverse performance requirements. Methodological approaches have evolved to enable designers harmonize the various specifications of functionality, safety, quality, reliability, and cost, aimed at achieving a broader spectrum of performances. Environmental awareness is another wave that has simultaneously swept the production process. Over the past decades, this has resulted in strategies to promote environment-friendly production, integrating environmental concerns with product standards. In product development, these new requirements involve a shift away from a conventional approach to an innovative approach. Specifically, it means considerations beyond the sale of the product to the end of the product's useful life and to its retirement (Adams, 2006).

Recently, countries and society pay more and more attention to improve environment and one of the objectives to gain importance for the companies is to create environmentally friendly products. One of the most striking areas where companies now have to be concerned is the environment. The concern regarding environmental impact stems from the fact that, whether we want it or not, all our products affect in some way our environment during their life-span. As a result, environment problems get more and more attentions in government, consumers and industries.

Product development is one of the most critical aspects for companies in reaching their sustainability objectives. However, the support needed for making sustainability related decisions are not systematically integrated in most companies today. So, it is a necessity to create generic methods and tools that helps the integration of sustainability aspects in decision making and product development. In order to reach such an objective, it is necessary to know the available design tools, main differences in their approaches and the synergies in between.

Taking the above points into consideration, the main objective of this thesis is to understand how and what companies are doing currently to integrate sustainability into their products and product design processes. We intend to identify the gap between the literature and the practice in order to help researchers in the future to develop a modified or a new method of integrating sustainability criterions into the product development processes that fill the existing gap.

Within the framework of this research, first we identify the methods and tools available in the literature; those integrate sustainability into product design and development. Then after identifying the main differences between existing methodologies and tools, we go further to identify the gaps between what is told in the literature and what is applied in practices of the companies. Next, based on the results from our survey, case studies and the literature reviewed, we try to figure out how and what companies are doing currently to integrate sustainability into their product and product design processes.

This work tries to focus on company characteristics, sustainable strategies and applications of the company, ecodesign tools and relevant product development processes in order to find an answer to above questions. In general, it aims at better understanding the actual state of sustainability practices within industrial companies.

To pursue this aim, an explorative research has been implemented through the use of a developed on-line questionnaire considering the objectives of our research, proposed to over 200 companies mostly located in Italy. For those enterprises that could not reply directly to the questionnaire, there was the possibility to send back the questionnaire by email. Because of the scarce number of replies, three case studies have been carried out in order to figure out the practices and applications better.

The output of this paper will help those who want to pursue a research in the area, to include sustainability dimension in product development course, and for those companies who are interested to understand and adopt tools and methods that is suitable for their company.

2.3. Research Objectives

Objectives are identified related to three sub-classes:

1) Company Characteristics
2) Ecodesign/sustainability tools

3) NPD Processes

As in the thesis, sustainable product design by using appropriate ecodesign tools and the concerning applications in companies are on focus, we identify the objectives in these three dimensions.

2.3.1. Objectives Related to Company Characteristics

- To understand what sort of voluntary (e.g. ISO 14001 and others) and mandatory [e.g. WEEE (electric/electronics), ELV (for automotives), RoHS, REACH …] policies companies are adopting.
    - To understand whether companies generally implement sustainable product design in order to conform to regulations or they do it voluntarily. To point out the level of existence of such policies/regulations in the industries.
- To assess the incentives for design changes, incentives from legislation, customer or competition
    - It is necessary to understand if the forces are able to make industries change their product designs. There are several motivating factors for a company or organization to become more environmentally responsible. Some of the most notable are:
        - ✓ Legislation: For example, the US Clean Air Act has limited the use of a number of materials and (European) take-back legislation is driving Design for Recycling efforts.
        - ✓ Customer demand: Awareness of environmental issues is increasing among customers. Some customers will even pay more for a product if it is green. Also, industrial customers (e.g., Original Equipment Manufacturers) do not want (future) environmental liability for a supplier's product.
        - ✓ Eco-Labeling programs: How "green" is a product? Having an eco-label becomes a competitive advantage.
        - ✓ ISO 14000: The ISO 14000 (environmental management standards) certification may become a crucial element in doing business, like ISO 9000 (quality management standards). In addition, many have noted that "Design for the Environment" (DFE) makes good business sense and has many other positive effects. For example, the reduction of material diversity leads to less diverse inventory, volume purchasing, and the opportunity to focus on a reduced number of (core) manufacturing

processes. (Bras, B. 1997).

  - It is useful to know the major motives of companies for sustainability. To understand the major forcing factors and their roles in the companies to focus on sustainability; the roles of legislations, customers and competition is important.

- To determine the level of investments on sustainable products
  - This knowledge may let us have a general idea about the importance given to sustainable product design practices in companies.
- To identify the internal changes occurring after adopting Ecodesign/sustainability tools.
  - In many cases when environmental aspects are integrated in product development, it leads to synergies with other business interests, like image improvement, new market opportunities and sometimes cost reductions, even in the short term (Hochschorner and Byggeth, 2005). We need to understand if employed ecodesign/sustainability tools lead to internal changes in the company and to what extent is this impact. It is necessary to know the effects of ecodesign implementation on companies.
- To check whether the companies' sustainability related decisions mostly depend on economic variables, environmental variables, social impacts or holistic approach.
  - It is unlikely that a company will make a choice that is not primarily economically driven. Furthermore, it is of crucial importance that new products meet market requirements. Therefore, there is a risk that the environment will not be the highest priority in some trade-off situations (Hochschorner and Byggeth, 2005). We aim to determine the main decision variable for companies' applications. It is helpful in determining whether the environment is of major concern also.
- To identify the importance of employing ecodesign tools among sustainability practices of companies
  - There are various sustainability practices carried out in companies and use of ecodesign tools is one of them. The aim here is to identify the role, share of ecodesign tools application among all sustainable practices, as it is main concern in our thesis regarding sustainability implementations.
- To understand whether the companies have plans/strategies to increase perception of their customers on their sustainability practices; whether they are successful in increasing the awareness of customers.
  - How customers perceive offers has been neglected in the research and practice of Ecodesign and the focus of Ecodesign has been rather in its technical aspects (Sakao,

2009). Therefore, communication to many stakeholders has to be organized. A systematic communication is necessary for an increase of acceptance. This communication has to enable all life cycle stakeholder to improve the overall environmental effectiveness and efficiency of the product system (Schmidt and Quella, 2003). The importance of the environmental sustainability of industrial products and processes derives not only from the ever stricter-becoming environmental legislations issued in most of the developed countries, but also from the higher awareness of customers concerning environmental problems. (Sakao and Fargnoli, 2008). The aim here is to analyze the validity of this belief.

- To understand the level of investment of the company on sustainable products compared to R&D costs
    - Level of investment compared to R&D costs is a good measure to evaluate the importance given to sustainability in companies
- To identify the distribution of the dependence of the company's decisions on economic, environmental and social aspects.
    - There are 3 main pillars of sustainability: Economic, environmental and social aspects. It is important to know companies' dependence frequency on these aspects
- To identify the companies' consideration of important factors during product design
    - 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. We aim to identify the importance of these factors for the companies and to see where environmental consideration stands among these.
- To determine what kind of benefits companies get by applying eco-design
    - These new approaches of ecodesign 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.
- To identify the mostly used environmental parameters for evaluating environmental aspects in product design
- To understand the driving factors for the company to implement ecodesign

- To identify the barriers faced standing in the way of the suggested ecodesign improvement options and the frequency of such barriers
- To determine the internal stimuli (reasons why ecodesign option is interesting, regardless of the influence of external parties) regarding the companies' sustainable product design

2.3.2. Objectives Related to Ecodesign Tools

- To determine the frequency of the use of ecodesign tools in companies' product design processes
  - To see the prevalence of use of ecodesign tools in practice
- To identify commonly used ecodesign tools in practice
  - To have a general idea of mostly preferred ecodesign tool in order to find the relevance of tools to company size and sector.
- To identify the users of these tools in practice
  - If the usage of the tools need technical knowledge, training, expertise that would limit its usage by others.
- To identify the NPD process phases in which the tools are employed
  - To understand the phases that are more suitable/preferred to use ecodesign tools and to identify the degree of implementation in early phases. Some tools, e.g. checklists for choosing chemicals (Volvo's Lists) are useful, early in the design process. Tools that are used for comparing different alternatives (e.g. Philips Fast Five Awareness, Econcept Spiderweb) are intended for later stages of the design process, when there are different product concepts to be compared. Other tools can be useful in several phases of the product development or procurement processes, for example tools to compare alternatives (e.g. Environmental Objectives Deployment (EOD), Funktionkosten) or tools to identify environ- mentally critical aspects of products (e.g. the MECO Method). (Hochschorner and Byggeth, 2005).

    Some of the tools can be complemented with other tools, for example checklists, which make them more applicable for guidance (e.g. the MET-Matrix and the Environmentally Responsible Product Assessment Matrix (ERPA)). (Hochschorner and Byggeth, 2005).
- To figure out the impact of ecodesign tools on time and cost of product development
  - A competitive product must address cost and time-to-market. Cost and time is important factors that affect decision making and decisions in the companies consider these two dimensions. It is necessary to know the effects of ecodesign tools on time and cost as selection of the tool may depend on these constraints.

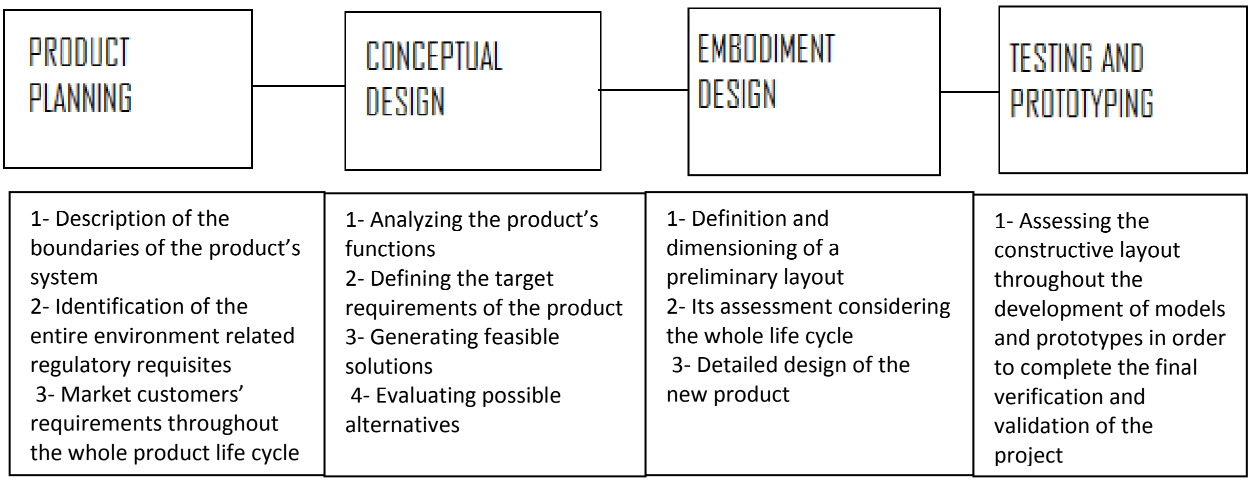
- Try to understand how they assess and improve reliability of tools and results of them
    - During the implementation of concerning tools, companies need to assess the results and try to improve the reliability of tools. It is crucial to relate the results obtained to product design according to design objectives.
- To decide if there is any mechanism employed to support trade-off, if the criteria in the used tools are weighted
    - Trade-off situations often occur in the product development process when alternative solutions emphasize different aspects that have to be balanced against each other. (Hochschorner and Byggeth, 2005). For different aspects several solutions are possible because we have to find compromises between several sometimes contradictory environmental aspects. For example energy consumption and weight of materials have to be balanced with the costs, etc. Decision making tools like a cost/benefit analysis can be applied to choose the best alternative (Schmidt and Quella, 2003). In order to support different trade-off situations, the tool should include criteria in a sustainability perspective within one environmental aspect (e.g. between different materials or different energy sources), between different environmental aspects (e.g. between energy use and level of toxicity) and between other important aspects (e.g. cost, social aspects, service) and environmental aspects (e.g. material use in relation to cost). It is necessary to understand if there are such mechanisms existent to support these types of trade-offs to make the right choices (Hochschorner and Byggeth, 2005).
- To identify the criterion to choose ecodesign/sustainability tools
    - It is of vital importance to understand how companies decide to use which ecodesign tool to use in their practices. It would foster our knowledge concerning the context of use of the ecodesign tools in relation with company characteristics.
- To identify the characteristics of the prevalent used tools (e.g. Qualitative vs. Quantitative, Need for training or workshops, Need of expertise, whether a life cycle approach is adopted, General vs. specific etc…)
    - It is important to know and understand what type of tools are mostly used in practice and the characteristics of them. E.g. Qualitative vs. quantitative tool selection may depend on the availability of data and time objectives. Generic vs. specific tools selection might be related to pace of applicability. Ecodesign techniques may not have been more widely adapted by businesses because such methods are not necessarily generic and immediately applicable but instead must include some form

of process-specific customization prior to use. To know if there is a need of expertise or training in order to effectively use ecodesign tools is important as existence of such needs as tools would remain just for the use of experts.

- To check if the application of ecodesign tools and methods by SMEs are limited as mentioned in literature
    - Despite the progressive use of ecodesign in the industrial world, taking into account environmental constraints remains problematical for small and medium sized enterprises (SMEs), which seem to be remaining on the fringe of the movement. Beyond the lack of environmental culture in the enterprises, the problem stems from the ecodesign tools which have not been designed with any thought of integrating them into the enterprises' organization. Baumann (2002) and Schiske (2006) indicate that the application of ecodesign tools and methods by SMEs are limited. It is useful to analyze the validity of this approach.
- To understand what level of design (e.g. product improvement, product redesign, new product concept definition, new product system definition) companies use ecodesign tools for
    - There are different levels of design that the ecodesign tools would be used in. To understand for what kind of design the companies use the ecodesign tools mostly is one of our objectives.
- To identify the reason for lack of adoption of ecodesign tools
    - Use of ecodesign tools is not common in companies' practices. The main reason here is to understand the rationales behind this.

2.3.3. Objectives Related to NPD Processes

- To identify the level of integration of the tools along the different NPD process phases in the companies is our intention.



- To identify the severity of the adverse environmental impacts observed in the following life-cycle stages
    - 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. We intend to classify lifecycle stages due to their impacts on environment based on feedback from the companies.
- To identify the frequency of different types of ecodesign (i.e. Product improvement, Product redesign, New product concept definition and New product system definition)
    - There are four types of ecodesign stages in accordance with the degree of achieving eco-efficiency (see figure 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. Our aim is to figure out mostly applied ecodesign type in practices.

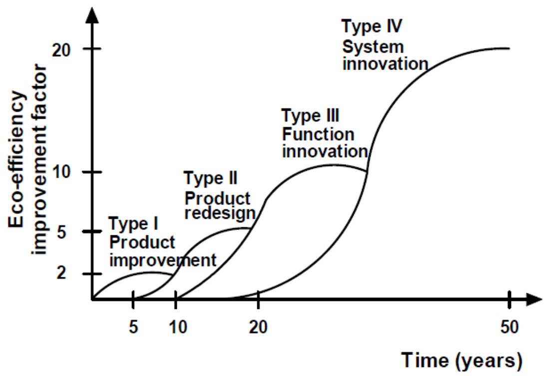


Figure 2: Four types of ecodesign (Rathenau Institute 1996)

- To identify the challenges of integrating sustainability in NPD process
- To understand How NPD process interrelate to other processes (manufacturing, purchasing, logistics) to guarantee sustainability
- To identify the effectiveness to address three bottom-lines of sustainability
- To decide whether companies consider sustainability approach in their product development processes

- To have an idea about the sustainable product strategies of the companies
- To understand if companies have any mechanisms to use the output of the previous ecodesign projects to improve the accuracy of the ecodesign tools
- To identify the prevalent types of failures during eco-design projects and the main causes for them

2.4. Significance of the Study

As already noted, the existing body of knowledge is far from extensive. There are quite a few papers and studies dedicated to sustainable product design, especially with a further focus on ecodesign tools. On the other hand there is increased professional, scientific and social interest in the area. Therefore as a general statement to start with, it can be noted that a paper dedicated to the topic could have substantial theoretical and practical significance especially because the area is quite unexplored.

The research conducted would contribute with the answers to some fundamental for the context questions. It is focused on the empirical aspect and from one side could serve as a picture (of course in the local context of the companies researched) for what the applications and practices in companies are regarding sustainable product design. This kind of state-of-the-art systemization could serve as a useful base for comparison with further researches.

Within the framework of the research; the considerations, applications and practices of companies would be explored and the gaps between theory and practices would be highlighted so as to understand what is missing in companies' applications and help develop a modified/new tool in order to eliminate these gaps.

The paper is going to be useful as well with providing insights on how and what companies are doing currently to integrate sustainability into their products and product design processes, with a focus on company characteristics, sustainable strategies and applications of the company, ecodesign tools and relevant product development processes. Of interest could as well be the explanations of those that are to serve as a reality check between what is being developed in theory and what implemented in the real business context.

Another strong benefit from this paper would be provided by the additional research dedicated to the identification of practical features that could help differentiate potentially dedicated to sustainable companies from non-sustainable ones.

2.5. Limitations of the Study

First of all, as most of the companies are not interested in such activities or do not apply such practices effectively, it is hard to make a detailed analysis on companies. So it is hard to get respond to requests from the industry side. Aligned with the previous statement, only 10 of the 200 companies replied to our on-line survey concerning sustainable product design, replying either they are not interested in the topic or they do not consider such approaches in their product design. It is not so hard to see that there is a huge difference between what is in the literature and what is applied in companies in current practices. This is a major limitation for our study.

Another limitation lies in the companies' responds to the questionnaire. For many of the questions, intentional or unintentional bias would be in the answers as some companies would be willing to see/show themselves more sustainable than what they really are. Even though, special attention had been given to avoid such issues when preparing the questions in order to minimize personal bias and distortions, it is not possible to eliminate such situations.

A potential weakness of the study is the impossibility to use a number of tools and techniques to compare the data obtained thanks to our on-line survey. For example because of the nature of the data (mostly qualitative) it is difficult to use a correlation analysis or other BI analysis techniques. Because of this a lot of the conclusions are to be extracted using mostly descriptive statistics.

3. LITERATURE REVIEW

3.1. Sustainability and Sustainable Development in General

Since the industrial revolution, the impact of human society on the ecosystem has been increasing exponentially. Men strive for increased welfare and prosperity, combined with a strong increase of the world's population, has led to ever more new products. Originally, the resulting increase of natural resource consumption and harmful emissions was not recognized as a major threat to society: raising the height of chimneys solved emission problems, while natural resources seemed inexhaustible. In the early 1970s, the Club of Rome rang the alarm bell, when predicting a running low of natural resources in their report "The Limits to Growth" (Meadows et al., 1972) At the same time, environmental legislation in the industrialized countries increasingly imposed limits on industrial pollution, thus stimulating the introduction of emission treatment equipment.

Since several years, the word sustainability has earned relevance within different backgrounds, even though its meaning is mainly related to environmental issues and social diseases. In fact, environmental changes and a higher awareness about social issues and poverty moved International Associations and different Countries to take extreme care of sustainability. As sustainability awareness increased more and more within many international associations, several definitions have been proposed, in order to define specifically its meaning and so to be able to face its main issues. (Kates et al., 2005)

The Brundtland Commission's brief definition of sustainable development as the "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland, 1987) is the most widely quoted definition of sustainability and sustainable development (WCED, 1987).

With this definition of sustainable development, in 1987 the World Commission on Environment and Development (WCED) mapped out what is now widely recognized as the guiding objective of the current process of economic and technological development: to ensure that the use of environmental resources to satisfy present demands is managed in a way that they are not left so damaged or impoverished they cannot be used by future generations. (Kates et al., 2005)

The use of this definition has led many to see sustainable development as having a major focus on intergenerational equity. Although the brief definition does not explicitly mention the environment or development, the subsequent paragraphs, while rarely quoted, are clear. On development, the report states that human needs are basic and essential; that economic growth is required to sustain them; and that equity is encouraged by effective citizen participation. On the environment, the report also mentions the limitations imposed by current technology and social organizations on environmental resources.

In the years following the Brundtland Commission's report, Board on Sustainable Development of the U.S. National Academy of Sciences focused on the seemingly inherent distinction between what advocates and analysts sought to sustain and what they sought to develop, the relationship between the two, and the time horizon of the future (Figure 3), in its report "Our Common Journey: A Transition toward Sustainability" (NRC, 1999).

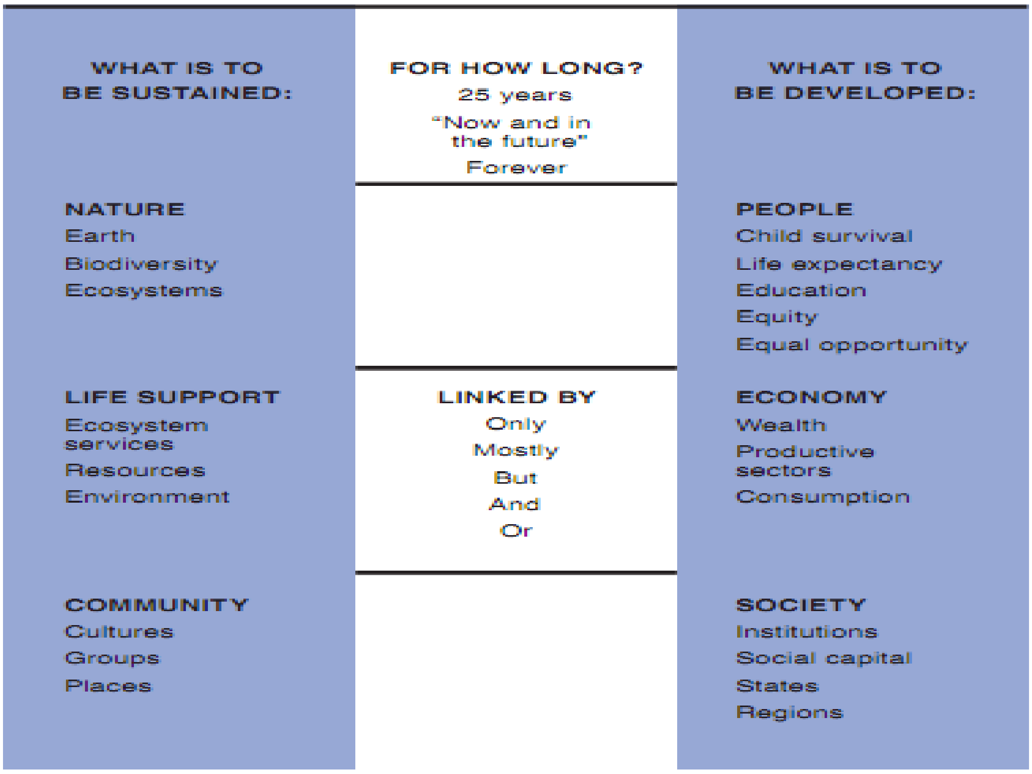


Figure 3: Definitions of Sustainable Development (NRC, 1999).

Similarly, there were three quite distinct ideas about what should be developed: people, economy, and society. Much of the early literature focused on economic development, with productive sectors providing employment, desired consumption, and wealth. More recently, attention has shifted to human development, including an emphasis on values and goals, such as increased life expectancy, education, equity, and opportunity. Finally, the Board on Sustainable Development also identified calls to develop society that emphasized the values of security and well-being of national states, regions, and institutions as well as the social capital of relationships and community ties. (NRC, 1999).

Many of the academics with an interest in sustainable development in the late eighties and early nineties approached the subject from an economics background (i.e. Dasgupta, 1993) attempting to price the environment through a framework of fiscal controls and incentives. This argues that the best way to protect the natural environment is to assign it an economic value based on people's willingness to pay. The aim is to internalize all the external costs to the economy in terms of pollution, resource depletion and human health. There have been numerous criticisms of this approach, including how to price irreplaceable resources, how to ensure equitable or fair distribution, or both, within and between nations, and how to reflect the resource needs of future generations within the current market place. Indeed, Aubrey Meyer has gone as far as to describe the approach as "the economics of genocide"

Another popular approach has been the environmental utilization space concept (Opschoor, 1987). This aims to reflect limits or thresholds to the amount of pressure that the ecosystem can withstand without irreversible damage and to use these to determine the operational boundaries of the environmental space that can be utilized. The ecological footprint method applies a similar set of conceptual principles.

In seeking a schematic vision, the socio-cultural, economic, and environmental elements representing the principal factors involved in the process of sustainable development, can be imagined as ideally placed at the vertices of an equilateral triangle (Munasinghe, 1993). The graphical representation in Figure 4 evidences the interactions between these key elements which must be harmonized for sustainable development. The center of the triangle, the point of equilibrium between the three factors, represents the condition where sustainable development is fully achieved, while all other points represent conditions where some elements have a different weight in defining the direction of development. The points on the edges of the triangle, for example, represent conditions where only two factors are considered, excluding the third.

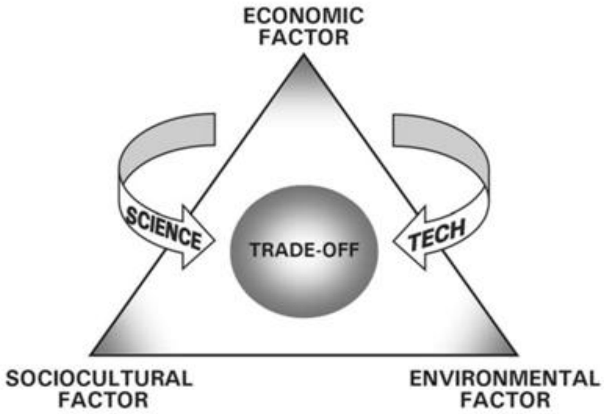


Figure 4: Triangle of sustainable development and the role of science and technology (Munasinghe, 1993).

In this view, scientists are placed in direct relation to each of the key factors and must provide information and tools to reinforce choices aimed at the best equilibrium (Munasinghe and Shearer, 1995) to achieve the desired condition of balanced, sustainable development.

After several decades of debate, therefore, the competencies of the actors involved in industrial development seem to have been delineated (O'Brien, 1999): industry must acquire the knowledge and capacity to assume its responsibilities in the development of sustainable production systems, while government has the responsibility of creating those socioeconomic conditions that allow companies to perform this task without losing competitiveness. In this scenario, research and development policies assume fundamental roles.

The 2005 World Summit on Sustainable Development marked a further expansion of the standard definition with the widely used three pillars of sustainable development: economic, social, and environmental. (United Nations General Assembly, 2005). This view has been expressed as an illustration using three overlapping ellipses indicating that the three pillars of sustainability are not mutually exclusive and can be mutually reinforcing.

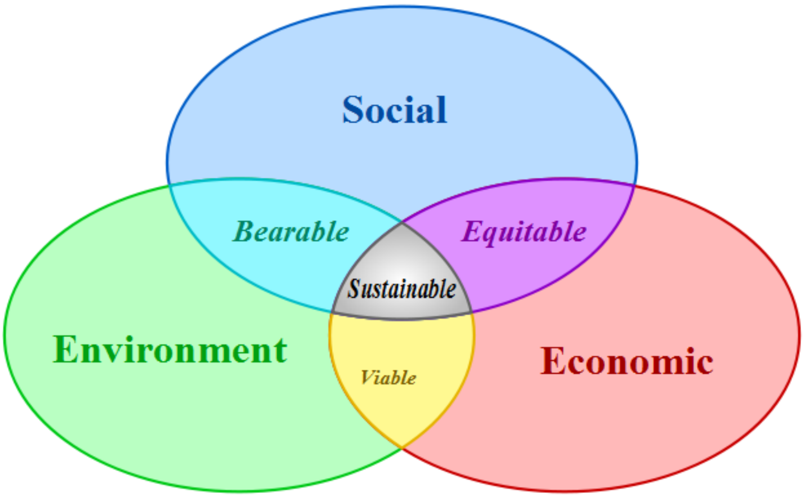


Figure 5: Scheme of sustainable development: at the confluence of three constituent parts (Adams, 2006).

The Johannesburg Declaration created "a collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development-economic development, social development and environmental protection-at local, national, regional and global levels. (Johannesburg Declaration, 2002)

In so doing, the World Summit addressed a running concern over the limits of the framework of environment and development, wherein development was widely viewed solely as economic development. For many under the common tent of sustainable development, such a narrow definition obscured their concerns for human development, equity, and social justice (United Nations General Assembly, 2005).

The last 40 years or so have seen a more attentive examination of the factors characterizing the processes of development in industrialized countries, evidencing the environmental risks implicit in an industrial development conditioned exclusively by economic mechanisms. One result of the new comprehension of the limits to resources and of the risks from phenomena of pollution is the concept of sustainable development.

This advocates the reconciliation of processes of development with respect for the environment, in the interests of future generations. Going as far as drawing an analogy between the processes of natural transformation and those of industry, sustainability concepts take inspiration from the teachings of nature in seeking to optimize the flows of resources characterizing the whole industrial system and the life cycles of products. From this perspective, whether directed at processes or products, the design phase is that stage in the life of systems or products with the greatest potential.

Currently, Sustainability is taking ever greater public attention and debate. The subject ranks high on the legislative agendas of most governments; media coverage of the topic has proliferated; and sustainability issues are of increasing concern to citizens around the world. (BCG, 2009)

However, the business implications of sustainability merit greater scrutiny. Will sustainability change the competitive landscape and reshape the opportunities and threats that companies face? If so, how? How worried are executives and other stakeholders about the impact of sustainability efforts on the corporate bottom line? What are companies doing now to capitalize on sustainability-driven challenges? And what strategies are they pursuing to position themselves competitively for the future?

3.2. Sustainability in Manufacturing Industries

3.2.1. Introduction

Sustainability is recognized as an important concept by modern organizations for survival in the competitive world (Bevilacqua et al., 2007). Those organizations are forced to adopt practices that are designed to maintain environment safety and minimize energy utilization. Sustainable organizations reduce production cost and prevent environmental problems for maintaining clean and green atmosphere (Senthilkumaran et al., 2001). Green system integrates product and process design issues with production planning and control to identify, quantify, assess and manage the flow of environmental waste with the ultimate goal of reducing environmental impact (Azzone and Noci, 1996). Green system tries to maximize resource efficiency for the production of sustainable components. Sustainability is the critical intersection between factors like manufacturing and product design practices and the environmental issues and concerns (Rusinko, 2007). Prevention of environmental problems tries to reduce the total life cycle cost of the products and thereby ensuring sustainability (Kaebernick et al., 2002). For the past one decade, the need for introducing environmental requirements into design and development of products is becoming a vital issue. The question of applying how to infuse environmental criteria into product design and how to compare environmental requirements with traditional design requirements is gaining vital importance (Brent and Labuschagne, 2004).

Current product design practices are based on traditional cost/profit models with a focus of achieving high quality at low cost and high profit. Environmental requirements generate additional design constraints and increasing costs (Kaebernick et al., 2002). In normal product design practice, environmental awareness is done later in the product development process and is not integrated with existing activities. The integration of environmental requirements into every stage of product development leads to the development of sustainable paradigm for manufacturing (Conteras et al., 2009).

Identification of new environmental features of product that possess potential to improve overall quality of a product increases additional market potential and gains (Soriano and Kaebernick, 2000).

Environmentally-driven activity and greater resource efficiency is good business, as far as manufacturers are concerned. That's because the pressure on manufacturers to improve their processes and technologies is no longer merely a matter of economics and costs. Currently, it comes from environmental legislation and the expectations of society too. Meeting those demands for a reduction in resource use requires behavioral and technological change and taking a systems view of manufacturing. Fortunately, leading-edge organizations are already showing the way here and there is a lot that can be learnt (Senthilkumaran et al., 2001).

This environmental activity is increasingly common in manufacturing businesses to address the triple bottom-line components of people, planet and profit: namely accounting for societal needs, the growing evidence for global warming, and the need to reduce costs. The drivers include both the opportunity costs of reducing the consumption of resources, and the requirements and punitive costs from increasing legislation. The pressures on manufacturers for change are many and varied. Some arise externally, such as legislative change, customer demands and pressures from wider society. A common example is customers who demand evidence of sustainable manufacturing activity (Brent and Labuschagne, 2004).

Other pressures are associated with the key resource flows in and out of a business, i.e. materials and energy on the one hand, and product and waste (including CO2, of course) on the other. Although manufacturers are putting considerable work into becoming leaner, improving performance and efficiency, and removing waste, they are only now paying more attention to less visible forms of waste such as power and heat loss, leakage and inappropriate use of compressed air, and unnecessary water use (Ball, 2010).

Many of the practices that manufacturers are adopting are practical and simple, but that does not mean they should be undervalued. They are often relatively easy to implement, require little investment and produce significant savings.

In many of the examples of sustainability programs, manufacturers credit an external influence with initiating the activity, such as a key customer, or transferring onto a new energy tariff. However, once the program has started, it is clear that internal leadership is the key just as it is with lean manufacturing and other improvement campaigns. The leaders in these companies are relentless in promoting sustainable manufacturing and challenging all staff to reduce waste of all forms and thereby reduces costs (Ball, 2010).

While the pressures on manufacturing to become more sustainable are increasing, and so is awareness of this imperative, the techniques to support manufacturers are still developing. New technology allows energy to be generated more cleanly and enables processes to consume less material and energy, but these new technologies must be effectively combined with existing technologies and facilities.

The traditional approach to environmental management in the manufacturing industry has evolved from pollution control (end-of-pipe approach) as preventive strategies. Driven by new legislations, increasing costs of raw materials and consumer demand, producers are expected to be more conscious of the ecological consequences of their industrial activities, and need to take preventive actions to minimize the environmental impacts. This increased attention to the environment is presenting manufacturers with new challenges ahead. In light of increasing pressures to adopt a more sustainable approach to product design and manufacture, the requirement to develop sustainable products is one of the key challenges facing industry in the 21st century

Manufacturing industries have the potential to become a driving force for realizing a sustainable society by introducing efficient production practices and developing products and services that help reduce negative impacts. This will require them to adopt a more holistic business approach that places environmental and social aspects on an equal footing with economic concerns. Their efforts to improve environmental performance have been shifting from "end-of-pipe" pollution control to a focus on product life cycles and integrated environmental strategies and management systems. Furthermore, efforts are increasingly made to create closed-loop, circular production systems in which discarded products are used as new resources for production (OECD, 2009).

The primary goals of a sustainable society concern the creation of material wealth and prosperity, the preservation of nature and the development of beneficial social conditions for all human beings. Interest in creating a sustainable society has been building among politicians, business leaders and the general public. This is particularly evident in the current debate on climate change and the level to which the issue has risen on the global political agenda, especially after the economic crisis which began in 2008 (OECD, 2009).

Manufacturing industries account for a significant part of the world's consumption of resources and generation of waste. Worldwide, the energy consumption of manufacturing industries grew by 61% from 1971 to 2004 and accounts for nearly a third of global energy usage. Manufacturing industries are also responsible for 36% of global carbon dioxide (CO2) emissions (IEA, 2007). However, these figures do not cover the extraction of raw materials and the use of manufactured products; if they did, the impact would be far greater. To date, manufacturing industries have taken various steps to reduce environmental and social impacts, largely owing to stricter regulations and growing pressure to take more responsibility for the impact of their operations. There is also a growing trend for companies to voluntarily improve their social and environmental performance for reasons relating to higher profitability, increased efficiency and greater competitiveness. As a result, industries are gradually moving from pollution control and treatment measures to more integrated and efficient solutions.

Nonetheless, the urgency of further action to avoid continuing environmental degradation is widely recognized. Improvements in resource and energy efficiency in some regions have often been offset by increasing consumption in others, and efficiency gains in some areas are outpaced by scale effects. The International Energy Agency (IEA) predicts that the global energy-related CO2 emissions will increase by 25% by 2030 even under the current best policy scenario (IEA, 2007). This emphasizes the need to alter patterns of production and consumption so as not to put further pressure on the planet.

Hence, the pressure on manufacturing industries to reduce their environmental and social impacts is bound to increase further. At the same time, they can become a driving force for the creation of a sustainable society by designing and implementing integrated sustainable practices that allow them to eliminate or drastically reduce their environmental and social impacts. (OECD, 2009)

They can also develop products that contribute to better environmental performance in other sectors. This calls for a shift in the perception of industrial production from one in which manufacturing is understood as an independent process to one in which it is an integral part of a broader system (Maxwell et al., 2006). This in turns requires the adoption of a more holistic business approach that places environmental and social aspects on an equal footing with economic concerns.

With the shift from pollution control to pollution prevention, environmental considerations and the improvement of environmental performance in manufacturing industries are also increasingly regarded from the perspective of business interests rather than regulatory compliance. In many cases, companies have found that what is good for the environment is not necessarily bad for business. In fact, it may lead to a competitive edge because of better general management, optimization of production processes, reductions in resource consumption. “Going green” is progressively seen as a potentially profitable direction, and voluntary and pre-emptive sustainability initiatives have become increasingly common in recent years. (Dewulf, 2003).

A range of developments in the global economy are strengthening the demand for greater efficiency. The globalization of manufacturing production and its value chain, for example, is strengthening competitive pressures, and the need for manufacturing companies to improve their cost-effectiveness is increasing. Combined with growing resource constraints, which have led to higher costs of core manufacturing activities, incentives to ensure resource efficiency are becoming stronger (Graedel and Allenby, 1995).

Over the last decade, the original idea and importance of eco-efficiency as a guiding principle for industrial production and business decisions has gained much broader attention and has been promoted with a simple catchphrase “doing more with less”, i.e. producing more goods and services while using fewer resources and creating less waste and pollution (EC, 2005).

This movement has led to a diverse range of conceptual and methodological approaches such as environmental monitoring and auditing and environmental strategies (Maxwell et al., 2006), which companies can use to implement eco-efficiency principles in production. Such tasks are not trivial for manufacturing companies and place great demands on their organizational management capability. The development of environmental management systems (EMSs) has tied together many of the environmental monitoring and management principles, providing a framework for companies to move towards eco-efficient production (Johnstone et al., 2007).

To sum up, the thinking and practices surrounding sustainable manufacturing have evolved in several ways in the last decades, from the application of technology for the treatment of pollution at the end of the pipe through prevention of pollution to minimizing inputs and outputs and substituting toxic materials. Recently, manufacturing companies have focused on solutions that integrate methods of minimizing material and energy flows by changing products/services and production methods and revitalizing disposed output as new resources for production. Advances towards sustainable manufacturing have also been achieved through better management practices.

Environmental strategies and management systems have allowed companies to better identify and monitor their environmental impacts and have facilitated improvements in environmental performance. Although such measures were initially limited to plant-specific production systems, they have evolved towards support for better environ-mental management throughout the life cycle of products and the value chain of companies. More integrated and systematic methods to improve sustainability performance in manufacturing industries have laid the foundation for the introduction of new business models such as PSS which could lead to significant environmental benefits. (Dewulf, 2003).

Furthermore, although still few in numbers, more efficient and intelligent ways of structuring production systems are being established, such as eco-industrial parks in which economic and environmental synergies between traditionally unrelated industrial producers are harnessed (Figure 6) (OECD,2009)

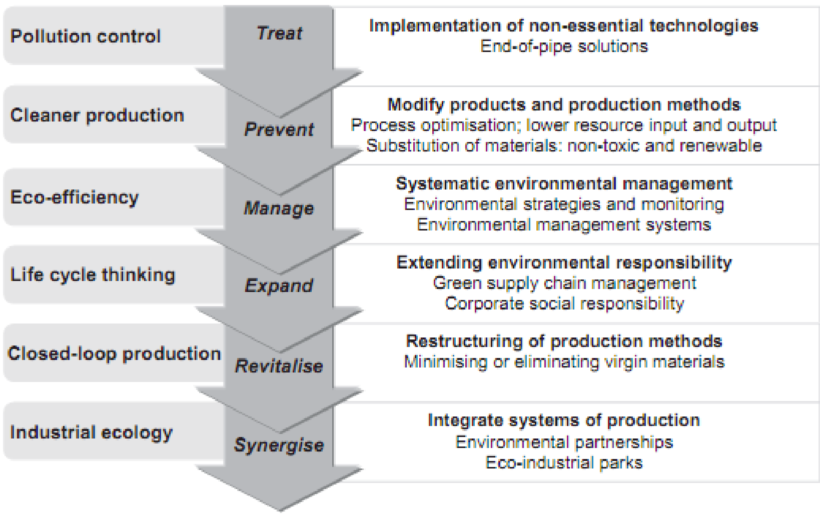


Figure 6: Evolution of sustainable manufacturing concepts and practices (OECD, 2009)

3.2.2. Paradigms for the Industry

A number of paradigms have been launched over the years to realize the goal of sustainable development from industry's side, such as:

Industrial ecology, defined as the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them (Graedel and Allenby, 1995).

Eco-efficiency, introduced at the Rio world summit of 1992 by the World Business Council on Sustainable Development (WBCSD) as the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity (Schmidheiny, 1992). It is proposed as a business strategy for implementing the concept of sustainable development, encouraging business to search for environmental improvements that yield parallel economic benefits. Thus, it is concerned with creating more value through less impact.

Cleaner Production, introduced by the United Nations Environmental Program (UNEP) as the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment. Cleaner Production can be applied to the processes used in any industry, to products themselves and to various services provided in society. For production processes, Cleaner Production results from one or a combination of conserving raw materials, water and energy; eliminating toxic and dangerous raw materials; and reducing the quantity and toxicity of all emissions and wastes at source during the production process. For products, Cleaner Production aims to reduce the environmental, health and safety impacts of products over their entire life cycles, from raw materials extraction, through manufacturing and use, to the 'ultimate' disposal of the product. For services, Cleaner Production implies incorporating environmental concerns into designing and delivering services.

3.2.3. Regulatory and Voluntary Standards for the Industry

Environmental legislation is increasingly stringent on both national and supra-national levels. Moreover, its focus is shifting from mere production process oriented emission restrictions towards a product and a product life cycle perspective. Exemplary to this evolution are the efforts of, amongst others, the European Union to co-ordinate its actions in respect to products' environmental aspects into a comprehensive framework referred to as Integrated Product Policy (IPP). IPP is aimed at reducing the environmental burden of products and services throughout their life cycles by using a toolbox of instruments for both supply side (improving the supply of green goods) and market side (supporting the demand for green goods) (EC,2001).

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 (APEC, 2005).

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 (APEC, 2005).

The use and disposition of specific material inputs is increasingly subject to regulations intended to minimize environmental harm. The European Union uses the Precautionary Principle as a key element of its environmental policy. Its recent Restriction on Hazardous Substances (ROHS) and Waste Electrical and Electronic Equipment (WEEE) directives have already reshaped the electronics and computer industries; the newly enacted Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) directive will have an even more profound impact on a wide range of companies. Europe's actions affect all manufacturers and are likely to be adopted in other regions (Blus, 2007).

"Soft" requirements, while not legally enforceable, are also gaining momentum. The media and the market are beginning to demand that companies publish information about their product contents, corporate emission levels and climate action plans. Grass roots campaigns targeting the use of specific materials (such as polyvinyl chloride, or PVC) may affect consumer preferences, spur lawsuits and foreshadow regulatory action (Dewulf, 2003).

Voluntary certifications are yet another emerging market factor. Materials or products that comply with a published standard are eligible to use the seal in their marketing materials. The effort and expense of the certification process is offset by a growing market preference for environmentally superior options. The number and type of voluntary certification programs expands every year.

3.2.4. The Business Benefits of Sustainability

Various drivers can be identified for companies to increase their environmental performance and profile. While often finding their roots in the ethical and ecological considerations of different actors in the product life cycle, such as customers, authorities and company employees, they all can lead to smaller or larger business benefits. The increasing importance of environmental issues to manufacturers poses risks and offers opportunities.

Profitability

• Using less energy in the production process lowers overhead and product costs. Companies that lower their cost of goods and operations have more money to invest in R&D, upgrading plant or equipment or capital improvements, all of which can contribute to greater competitiveness and long-term success.

• Using fewer materials also cuts costs. Switching to more sustainable materials may or may not reduce costs at the front end, but will likely reduce waste, emissions and pollution, and perhaps avoid shortages or price increases for the less-sustainable material.

• Companies that use natural resources wisely and take positive steps to lower their environmental impact are more successful in attracting and retaining loyal customers and staff.

• Manufacturers that take responsibility for their products after point of sale can sometimes create an annuity-based service business.

Competition

• Sustainability is still a differentiator, but not for long–it is quickly becoming an expected part of doing business in the global economy.

• Customers claim in surveys that they are willing to pay more for a safe, healthy, green product. Recent concerns about the presence of dangerous chemicals and materials in imported goods give domestic manufacturers a chance to regain market share for some types of consumer goods.

• Products that use minimal energy and water during their useful life will cost less to own and operate than less resource-efficient alternatives.

Compliance and Managing Risk

• Regulatory pressures will continue to increase and expand to cover materials and products whose cumulative environmental impact is deemed unacceptable (such as non-biodegradable plastic).

• Pro-actively reducing the carbon and chemical footprint of a business now can avert or minimize negative regulatory impacts later.

• A sustainable approach reduces risks at every stage of business, leaving businesses less exposed to the possibility of materials shortages, energy price increases, higher fees for waste disposal and pollution abatement, liability and unwelcome shareholder actions.

Market Opportunities / Growth

• Major corporations and public agencies are increasingly demanding emissions reporting and mitigation plans from their supply chain partners.14 Suppliers who can show an understanding of the issues and progress toward goals will win business away from those that do not.

• Earning a valued third party certification designation puts products on the short list for businesses and government agencies that have implemented an environmentally preferable purchasing policy.

• Sustainability challenges are spurring the need for new solutions. Manufacturers that can add or extend an existing product line to meet the challenges have huge market opportunity.

3.3. Environmental Conscious Product Design

It is well known that although only 5-7% of the entire product cost is attributable to early design, the decisions made during this stage lock in 70-80% of the total product cost (Ullman, 1997). Correspondingly, one can hypothesize the same to be the case for environmental impacts. That is, whether or not a product is relatively sustainable is largely determined during the early design stage.

Due to high levels of uncertainty regarding design embodiments at the early design phase, novel methods and tools are essential to provide designers a basis for ascertaining the degree of sustainability of a given product or process (Sousa and Wallace, 2006).

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 (Schmidheiny, 1992).

In recent years, considerable innovation has gone into product design and management. The aim of innovation is to reduce time taken and resources used in design, production, distribution, and disposal of products with elevated and diverse performance requirements. Methodological approaches have evolved to enable designers harmonize the various specifications of functionality, safety, quality, reliability, and cost, aimed at achieving a broader spectrum of performances. Environmental awareness is another wave that has simultaneously swept the production process. Over the past decades, this has resulted in strategies to promote environment-friendly production, integrating environmental concerns with product standards. In product development, these new requirements involve a shift away from a conventional approach to an innovative approach. Specifically, it means considerations beyond the sale of the product to the end of the product's useful life and to its retirement (Adams, 2006).

Thus, environmental requirements must lead to innovations toward a successful and "sustainable" product design. A design approach directed at the systematic reduction or elimination of the environmental impacts implicated in the life cycle of a product, from the extraction of raw materials to product disposal, can help. This methodology, known as design for environment, is based on evaluating the potential impacts throughout the design process.

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.

The product manufacturing process is the main stage in the life cycle that consumes resources directly and produces environmental pollution as well as being the main factor that affects the result of enterprise performance in terms of sustainable development (Gutowski, 2004). Efforts to minimize the environmental impacts of manufacturing processes can roughly be classified into three categories: (1) process improvement and optimization, (2) new process development, and (3) process planning. Traditional manufacturing processes are generally designed for high performance and low cost with little attention paid to environmental issues.

Manufacturing companies' limited knowledge of the impacts of products on the environment is historically linked to producers needing to address principally those aspects regarding the impact at production sites (consumption of resources, generation of emissions and waste), not directly attributable to products and limited to the context of the production phase alone. The result has been a lack of primary information that could support a strategy to improve the environmental quality of products, requiring a vision extended over a product's entire life cycle (Chertow, 2001).

Traditional cost-oriented formulations of the development process stem from an outdated, defensive approach to the environmental question that considers the environment a restrictive and generally troublesome constraint, without being able to appreciate its potential positive value. This problematic factor becomes particularly significant when one considers the weight that cost planning and marketing functions have in the product development process. The lack of accurate economic analysis and a non-perception of a product's "environmental value" can seriously hamper eco-compatible design (Tischner et al., 2000)

The lack of a homogenous, environmentally oriented approach, thoroughly integrated into the entire development process, is one of the crucial factors. It has often been observed that this lack is usually most evident in the preliminary phases of product development (Bhamra et al., 1999) where there is a scarcity of methods and tools oriented toward environmental aspects. It should be noted how, more generally, design practice lacks an organic approach to environmental aspects in the entire development process, despite such an approach clearly being desirable at the theoretical level.

While the more important issues associated with the environmental aspects of industrial production are the subject of much discussion nowadays, manufacturing companies still have difficulty in achieving environmentally sustainable production. One of the crucial factors in this problem is that the principles and methods of designing for the environmental quality of products have not yet been integrated into design and managerial practice (Gutowski et al., 2004). The result is that the success factors in product design still remain limited to those of quality and development costs (i.e., to those that can be understood as factors associated with the product's impact on the business environment).

Despite a clear perception of the leading role design plays in resource transformation and consumption, a full understanding of its potential and responsibility toward the environmental question has been slow to arrive.

Considerations regarding the technical aspects of environment-friendly designs emerged in the first half of the 1980s (Overby 1979; Lund 1984). The early 1990s witnessed a phase of greater understanding of new needs to safeguard resources. This resulted in the clear objective of integrating environmental demands in traditional design procedures (Overby 1990; Navin-Chandra 1991; OTA 1992) and culminated in design for environment (DFE), green design (GD), environmentally conscious design (ECD), and ecodesign. This new approach aimed at minimizing the impact, on the environment, of products that were already in the design phase. (Gupta and Lambert, 2008)

Product design and development relating to improved environmental performance has many expressions including design for environment, ecological design, environmental design, environment conscious design, environmentally responsible design, socially responsible design, sustainable product design, sustainable product development, green design and life cycle design. Here we use the terms environment conscious design and design for environment (DFE).

DFE is a practice by which environmental considerations are integrated into product and process engineering design procedures. DFE practices are meant to develop environmentally compatible products and processes while maintaining product, price, performance, and quality standards (Graedel and Allenby, 2003). Sherwin and Bhamra (1999) suggested that the real focus for innovation should be around stages 3 and 4 (redesign and rethink), as can be seen in Figure 2 and in the original revised four-step approach by Charter (1997). Indeed, sustainability is inextricably linked with economic and social considerations that differ across cultures and technology, and combined with improved design; they can greatly aid this quest (Chertow, 2001).

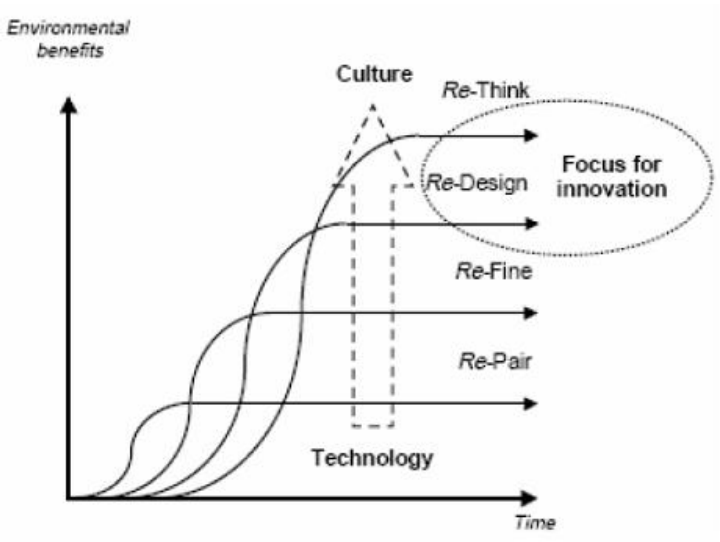


Figure 7: Revised Approach to DFS (Sherwin and Bhamra, 1999).

Design for the environment enables consideration of environmental issues as business opportunities. These opportunities may exist for new products, processes, or manufacturing technologies (Wukash, 1993). The extent of the product‘s environmental friendliness depends on the level of DFE implemented by the company. Therefore, most of the levels of DFE have to be set up before companies start to implement their own DFE. In general, because of the complexity of today's products and the departmental organization of most companies, DFE is essentially a cross-functional activity (Johansson, 2002). Although DFE suggests a number of ways in which one can include environmental considerations in design, it is prescriptive. It does not reflect reality, which is simply that the considerations and decisions at design time have to be informed by knowledge which comes from detailed analysis. However, such analysis takes a long time and is done at later stages of the product design process. Projection of lifecycle data to the design phase would enable key decisions at the early design phase. New interfaces and design methods must be developed and tested, using appropriate information/knowledge models to accomplish this task.

One of the most important aspects of Design for Environment (DFE) is that it can act as a connecting bridge between production planning and development and the environmental management of the same two functions that are usually separate. In order to fulfill this role, the design activity must have several ineluctable features: a product life cycle orientation; the balancing of a wide range of requirements; and a simultaneous and integrated structure of the design intervention. Only on the basis of these premises is it possible to conceive a process of product development that furthers the sustainability of its life cycle, with the ideal objective of obtaining a product whose manufacture, use, and disposal have the least possible effects on the environment (APEC, 2005).

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 (APEC, 2005). 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.

Environmentally conscious manufacturing (ECM) involves producing products such that their overall negative environmental effects are minimized ECM consists of the following two key issues:

1. Understanding the life cycle of the product and its impact on the environment at each of its life stages and

2. Making better decisions during product design and manufacturing so that the environmental attributes of the product and manufacturing process are kept at a desired level.

The first issue is necessary for drawing lines to determine how the product will evolve from the drawing board and how it will affect the environment throughout its life stages. If we fully understand the life cycle of the product, we can then transfer this information onto the actual development of the product. In addition, understanding the end-of-life stage of the product is critical since one of the largest impact on the environment occurs at that stage. During the design stage of the product, there are different objectives that the designers may focus on. Depending on the end-of life strategy of the product, the design of the product can be realized to increase recyclability manufacturability, disassemblability and to minimize the effect on the environment. When designing a product with environmental features, material selection should also be considered as a key element. Once the design decisions of a product are complete and the materials for its production are identified, the product's environmental attributes are pretty much set. However, in addition to design and materials decisions, issues involving selection of energy source, cooling systems and handling of hazardous by products, etc. must be controlled during the manufacturing process to achieve a complete ECM concept.

In addition to environmentally friendly product designs resulting from DFE initiatives, issues involving production must also be addressed to have a complete concept of environmentally conscious manufacturing. These issues include electing energy sources necessary for production, designing cooling systems and handling hazardous by products. Currently, numerous production techniques, material handling systems and energy sources are available.

Utilizing some sort of an assessment tool to select among them may be valuable financially as well as improve the environmental features of the production system. Bock develops a tool to come up with a good material and process combination. Similar models have been developed to analyze how the selection of different manufacturing processes effect the environment (Gungor and Gupta, 1998).

3.4. Ecodesign Tools

3.4.1. Introduction and Definitions

The most powerful and prevalent tools used in sustainable product design are those which consider environmental aspect of sustainability, so called "eco-design tools". Most of the tools in this category, intend to solve certain design problems as they are quite specific. It is important to have a clear idea about the preferred tools effectiveness in the type of situation that it is applied. The risks of misuse of the tools occur otherwise.

Many eco-design tools and methods exist: some are extremely simple and qualitative, while others are complex and quantitative. The selection of the best tool for a given application depends on the individual situation of the context of the design and development process.

Mistakes in selecting the most suitable tool depending on the specific situation may limit the effectiveness, usability and applicability of the tools. Criteria that should be taken into account during the selection of the adequate tools could be listed as following: (Sakao and Fargnoli, 2008)

- Level of information available
- The nature of data input
- The quality of the expected results
- The aim of conducting the study
- The time dependency of tool

- The type of business or product
- The intended user
- In what phase of the product it will be used
- In what kind of situation the tools are effective

The simplest classification of tools is into those which perform data analysis, and those, which are aimed at improvement. Analysis tools provide a measurement of the potential environmental impact of a product. They are mostly used before design starts, by analyzing a previous product or that of a competitor. Alternatively, they may be used at the end of a design project to verify the result. Improvement tools, on the other hand, are used during the design process to direct activity and provide information on the process.

The tools and methods for further analysis are chosen on the basis of the most documented tools in the revised literature and their contribution to the development of other methodologies. Besides these considerations for choosing the method and tools for evaluation, their usage combined with other tools and methodologies are taken into account as well.

LCA is an environmental management tool which identifies all resources used and wastes generated to all environmental compartments over the whole life cycle of a specific product (De Smet et al., 1996). It is the only standardized tool currently used to assess products and processes. The LCA methodology consists basically of four steps: goal and scope definition, inventory analysis, impact assessment and interpretation.

The goal and scope must clearly state the intended objectives of application, and define the system under study: its function, boundaries, hypotheses, data requirements, etc. Then the inventory analysis consists of a material and energy balance of the product system, aiming at the identification and quantification of substances that may be environmentally relevant. The environmental significance of these substances is assessed in the impact assessment phase, and finally the interpretation phase consists of discussing the results of the study in the light of the goals initially set (Sonneman et al., 2004).

LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g. raw material extraction, material transportation, ultimate product disposal, etc). By considering impacts throughout the product life cycle, LCA provides a comprehensive overview of the environmental characteristics of that product or process and a more accurate picture of the true environmental trade-offs in product selection (De Smet, 1996).

LCA (Sakao and Fargnoli, 2008) is a quantitative and objective assessment tool that is advantageous for collecting information but effort demanding techniques at the same time. In order to be used in the information collection step, previous generation products of same type should be already available and this could be considered as a disadvantage. Certainly, it works well in evaluation steps.

The power of LCA (Sonneman et al., 2004) is that it expands the debate on environmental concerns beyond a single issue, and attempts to address a broad range of environmental issues, by using a quantitative methodology, providing an objective basis for decision making. One of the main weaknesses of LCA derive from its holistic nature is that because of the lack of temporal and spatial detail in the inventory data, actual impacts cannot at present be assessed, but only so-called “potential impacts”.

LCA leads to improved product design. It can be used to aid decision-making during product, or process, design or re-design. Businesses can use LCA to compare the environmental impacts of different design options to assess whether they have potentially significant environmental advantages or disadvantages. In this way, LCA enables a systematic evaluation of the environmental impacts associated with a specific product (Azapagic, 2002).

Small Medium Sized Enterprises (SMEs) that use LCA will have several advantages over their competitors. They will be able to identify opportunities for waste reduction that will lead to a continuous improvement of their products and processes. At the same time, LCA is a tool that is recognized by regulators, legislators, scientists, consumer groups and environmental groups alike, and so it represents a common basis for the environmental quality assessment of products and processes (Hendrickson et al., 2005).

LCA has also some financial benefits. It examines a product’s life cycle and identifies where the main environmental impacts arise. These environmental impacts can be reduced by increasing the efficiency with which material and energy inputs are used. Increasing the efficiency of resource use will lead to a reduction in the quantity of inputs used and waste produced, thereby reducing costs (Hendrickson et al., 2005).

However, there are also some limitations of it related to product design: (Munoz, 2006)

- The assessment and improvement stages of LCA are not yet well developed. Assessment is probably the most difficult stage to accomplish. It is difficult to estimate all the possible environmental impacts of an activity product or process (health effects, ecological effects, etc.) as impacts are time and location dependent and may be synergistic or antagonistic.

- Availability of data is a limitation. Databases are being developed in various countries, but in practice, data are frequently obsolete, incomparable, or of unknown quality.
- As LCA requires detailed and complete product information, it is not suitable for early design.

No single tool can provide answers to all the questions posed by environmental issues. The limitations of LCA highlight the fact that in order to fill these gaps, other analytical tools must be added to given decision situations. There have been many researches, proposing methodologies and tools, independent or integrated, to achieve a sustainable product design.

The cost, time required, as well as the difficulties in gathering all the necessary data are the main drawbacks for carrying out a complete LCA study as mentioned above. This has encouraged practitioners to investigate the possibility of "streamlining" LCA to make it more feasible and more immediately relevant, without losing the key features of a life cycle approach (Todd and Curran, 1996).

Streamlined LCA is a simplified variety of detailed LCA, in which the scope, cost, and effort required is reduced. However, the border between detailed and streamlined LCA is not straightforward. In fact, according to Graedel (1998), a complete, quantitative LCA has never been accomplished, nor is it likely to be. This implies that, for all practical LCA studies, some form of streamlining is essential for feasibility; LCA practitioners do not decide whether to streamline, but where and how to streamline. Streamlining is, therefore, a disciplined process of designing an LCA study to gather enough information in order to make a sound decision (Todd and Curran, 1996).

A number of tools have been developed aimed at optimizing one single environmental aspect. The best-known types of single aspect tools are, however, tools aimed at optimizing the product end-of-life phase in general and the recycling and disassembly processes in particular.

These are so-called DFX (Design for X), as well, which groups a member of concepts, methods and tools aiming at optimization of some criterion X. Although in the majority of the studies in the literature DFX methods are characterized as focused tools. In the study of Dewulf (2003), it mentions that DFX is a family which groups number of concepts, methods and tools aiming at the optimization of some criterion X.

A further classification is made to distinguish two types of subfamilies within the DfX group. On the one hand, DfX_{virtue} tools and techniques, such as Design for Quality, are aimed at optimizing one property of a product over the full life cycle. On the other hand, $DfX_{Lifephase}$ tools and techniques, such as Design for Manufacturing, are aimed at minimizing the costs within one lifecycle phase. It is clear that ecodesign is a member of the former category, while Design for Recycling (DfR) belongs to the latter. Van Hemel (Meinders, 1997) warns that often a DfX_{virtue} is replaced by a more straightforward $DfXl_{ifephase}$ tool, e.g. when ecodesign is narrowed to merely DfR (Dewulf, 2003).

This "straightforward $DFX_{lifephase}$" tools are the ones that are generally referred within the literature and also in this study. This straightforward DFX is the systematic consideration of design performance with respect to environmental, health and safety objectives, but unlikely to DFE (which forms the upper level) these tools don't consider full product or process lifecycles (Choi et al., 2008).

DFX methods usually deal with a specific issue within all the issues that DFE should handle. Due to this, these methods are applied to a specific lifecycle stage (Dewulf, 2003).

In addition to this, QFD (Quality Function Deployment) based methods are also supportive in this context. They simply turn customer requirements and environmental needs into product features. In this context, Cristofari et al. (1996) integrated QFD and LCA with the aim of applying to product design and came up with the concept of Green QFD, which had been effective for evaluation concerning environmental requirements during life cycle. Then, QFDE concept was introduced by Masui et al. (2000), using QFD in environmentally conscious product design. In the study of Vinodh and Rathod (2010), ECQFD and LCA approaches are integrated to provide a sustainable product design. They implement the method for the processes of a manufacturing organization and prove the feasibility and compatibility of their methods in such an environment.

A method named GQFD-II that integrates LCA and LCC into QFD was proposed by Zhang et al. (1999), trying to integrate LCC into QFD matrices. GQFD-II elaborates the original GQFD, in which Life cycle Assessment and QFD are combined to evaluate different product concepts. GQFD-II includes three major phases. Phase I is the Technical Requirement Identification phase, where customer, environmental and cost requirements are established and documented. Phase II is called Product Concept Generation and a series of product concepts are generated to satisfy the requirements established from Phase I. These concepts can be evaluated with respect to quality, environment and cost. The best product concept is selected afterwards. Then follows the third phase: Product/Process Design. In this phase, the requirements from previous phases are deployed into all product/process design stages, so that a series of matrices can be established, including: design deployment, process planning, production planning, maintenance planning, and retirement planning.

GQFD-II is an efficient tool for product development or improvement by virtue of improving quality, reducing costs and minimizing environmental impacts. GQFD-II integrates LCA and LCC into QFD matrices and deploys customer, environmental and cost requirements throughout the entire product development process (Zhang et al., 1999)

Eco-design guidelines (Bras, 1997) are available on different levels of detail. On an upper level, design strategies are presented. These high level strategies are often used as a checklist after brainstorm improvement sessions in order to verify whether the entire range of eco-design improvement strategies has been explored.

Checklists are qualitative approaches that target distinct environmental design strategies such as material conservation, energy efficiency, and pollution prevention guidelines. Although an excellent starting point to raise environmental awareness, checklists are quite general and their use lacks the thought process that may lead designers to new opportunities. Also, checklists do not readily support subtle trade-off analysis (Schepper and Eisenhard, 2000).

Checklist method used in ECODESIGN PILOT (Wimmer and Züst, 2003) is easy to use thanks to low load on the users especially for the companies that would find it difficult to put much effort. However, the drawback is that checklist methods do not add a significant value to an improvement of a product concept in general. The goal of the method is to carry out a qualitative determination of the characteristics that have significant impacts on the environmental performance of the product. That’s why products are classified into 5 categories that are listed below:

- Type A: Raw material Intensive
- Type B: Manufacture Intensive
- Type C: Transportation Intensive
- Type D: Use Intensive
- Type E: Disposal Intensive

This method is very useful for an initial assessment of a product. The results obtained are simple, qualitative and allow rapid use depending on the user’s capability. The weakness of the Eco Design

Pilot is the reliance on qualitative analysis and the low transparency of the process of identifying suggestions. Thus, it is not sufficient alone to prioritize effectively the design modifications to be made in order to solve the related problems emerging from the checklists.

As combination of above mentioned two methods, Eco Impact Matrix (EIM) (Sakao and Fargnoli, 2008) stems from the idea to integrate specific design tools during the conceptual phase of design, which integrates Ecodesign PILOT and QFDE. Analyzing and selecting the best interventions by using Ecodesign Pilot, the methodology then applies QFDE on these priorities. Possible interventions to improve the environmental performances of the product would be determined with effective use of Ecodesign Pilot but the output obtained here does not give necessary information regarding the influence of the possible modifications on product life cycle. EIM is employed at this point as it also includes QFDE application afterwards to define and evaluate mutual relationships between these predefined priorities. Thus, the output includes measures to be applied for the environmental improvement of the product.

In the study of Sakao and Fargnoli (2008), it was mentioned that the integrated use of the ecodesign tools is effective to support designers in companies, even when there is a lack of specific background in the matter of design methodologies, as in the case of SMEs. Moreover, it was underlined the efficiency and effectiveness of ecodesign tools when used in a synergic way.

Ecodesign Strategy Wheel (Brezet and Hemel, 1997) is a useful assessment eco-design tool that has certain advantages of ease and effectiveness in providing results. The tool provides a basic framework that can be used systematically to review the entire life cycle of a product. It may also be used as a basis for brainstorming to highlight activities in a product's life cycle that may have an impact on the environment. The evaluation is grouped in 8 strategies.

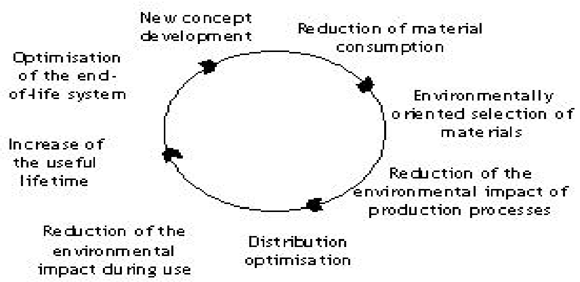


Figure 8: Eight Strategies of Ecodesign Strategy Wheel (Lids-Wheel) (Brezet and Hemel, 1997)

Life cycle of a product is completely covered by these strategies, helping designers improve their product performances environmentally with an effective decision making.. One good point about this method is the graphical representation of the results. The tool is mainly useful to stimulate the creative design process, assist in visualizing current environmental performance and highlight opportunities for improvement.

Environmental Effect Analysis (EEA) (Lindahl and Tingström, 2000) method is derived mainly from Failure Mode Effect Analysis (FMEA). However, unlike FMEA, which stresses potential failure risks, EEA emphasizes environmental effects during normal operations: it is used to identify and evaluate the potential environmental impacts in all life cycle phases of a product. It is useful to determine the source causes and the related environmental impacts and helps minimize the adverse environmental impact of the product's life cycle as cost-efficiently as possible. As it requires no quantitative information of a product, it could be applied to the earlier information collection and problem definition steps. EEA is a qualitative method primarily intended for internal use. (Widheden, 2002). The main difference, and at the same time the main advantage, in comparison with LCA is the sufficiency of qualitative data, which are more easily accessible. Moreover, EEA more explicitly addresses the questions causing the environmental effect and if possible to reduce it. Their disadvantage is caused from the unsuitability for the other life cycle stages.

The matrix methods (Dewulf, 2003) constitute an important group of life cycle thinking tools. The matrices are N by M assessment matrices, of which one dimension represents the life cycle stages and the other dimension represents the environmental aspects. Practitioners are then urged to think about every matrix cell: in every element, users write down potential environmental interventions. The simplicity of the approach lies at the basis of their success in industrial practice. Major disadvantage, however, is the potential lack of quality of the output: practitioners without a thorough knowledge and experience in the field of eco-design will easily ignore potential aspects or wrongly estimate their mutual importance. Consequently, this category of tools can be considered more as an aid for brainstorming sessions than as an analysis tool.

Qualitative matrices also promote life cycle thinking. Matrices provide an illustrative means for evaluating trade-offs and interactions among design criteria. However, their form limits the manipulation of information to assess new design strategies quickly when tradeoffs involve complex multi-objective functions (Schepper and Eisenhard, 2000).

The simplicity of the approach lies at the basis of their success in industrial practice. Major disadvantage, however, is the potential lack of quality of the output: practitioners without a thorough knowledge and experience in the field of eco-design will easily ignore potential aspects or wrongly estimate their mutual importance. Consequently, this category of tools can be considered more as an aid for brainstorming sessions than as an analysis tool (Dewulf, 2003).

Abridged LCA is a semi quantitative matrix approach. Like qualitative matrices, it highlights only the most significant concerns. An additional benefit of abridged LCA is its numerical basis, allowing for matrix manipulation and improved, but perhaps inconsistent, trade-off analysis as the quantitative elements are based on heuristics (Schepper and Eisenhard et al., 2000).

To overcome these disadvantages, variants of quantitative approaches have been developed, adding to each matrix cell a short checklist and questions in order to allow assigning a score to each matrix elements. While visibly being an improvement, the major problems of the simple matrix approaches remain unsolved: assigning the scores is highly subjective, and the weighting between the different matrix elements is either subjective or not done at all. A sensible weighting set would require a priori knowledge about the importance of different life phases an environmental stressors (Dewulf, 2003).

Some specific types of matrix methods are available in the literature. ERPA (Environmentally Responsible Product Assessment) is a Streamlined LCA tool introduced by Graedel and Allenby (1995) in the form of matrix that helps assess improvement potential of a product in terms of environment. It evaluates all life cycle stages on five criteria and confronts them to environmental issues (material, energy, residuals, etc…). As a result, it gives qualitative or semi-quantitative values. MECO (Material, Environmental chemical and others) matrix (Wenzel et al., 1997) is a semi-quantitative Streamlined LCA approach tool as ERPA. Here, environmental impacts are evaluated by the calculation and estimation of the amounts of chemicals, energy and materials. Brezet and Van Hemel (1997) presented MET-Matrix tool that intends to determine the most important environmental problems evaluating the life cycle stages of the product. The environmental problems are mainly classified in categories as Energy use, Toxic emissions and Material cycle. A completed matrix generates structured qualitative information on the environmental aspects associated with the production, use and disposal of a product. This information is largely based on the available knowledge and experience of the project team that performs the analysis.

Product Design Matrix (Sakao and Fargnoli, 2008) is a simple and easy to use tool that aims to define environmental impact of a product asking series of questions covering all the phases of product life cycle. It is a compilation of various guidelines that help designers assess the environmental performances of a product and provides a scoring system together with list of hazardous chemical pollutants and other useful resources. Drawbacks of the methods are that the tool is not improved recently and the information about the hazardous materials had not been updated since a very long time. On the positive side, it is useful during first steps of the product design process.

The "environmental indicator" (Dewulf, 2003) approach is commonly used in industrial practice. It eliminates the extensive data gathering efforts connected to tracing all life cycle processes and their related elementary flows (emissions, waste, material and energy) by making use of average data for common sections of a product life cycle. Based on these average data, an impact assessment is performed using one of the LCIA methodologies, thus leading to indicator scores. Eco Indicator 99 (Hemdi, 2009) is a tool based on this method, based on three main impacts that include human health, ecosystem and mineral resources. A target level is set for particular environmental effects and a weight is given for the seriousness of these impacts based on the gap between target level and environmental impact. It is a generalized tool compatible to evaluate any kind of products and easy to be applied by a designer without an in-depth knowledge of the environmental issues. However, the drawback is that the evaluation does not concern the analysis of cost and technology.

Restricted material list (Dewulf, 2003) is another tool. Many companies control the materials used in their products by means of restricted materials lists, composed through careful follow-up of standards, legislation and internal company research. Major asset of the tool is, of course, its easiness-for-use. Moreover, it provides a set of clearly defined environmental requirements, thus integrating the envisaged environmental aspects in the earliest phase of design.

Green Fuzzy design Analysis (GFDA) is a method developed by Kuo, Chang and Huang (2006) which involves simple and efficient procedures to evaluate product design alternatives based on environmental consideration using fuzzy logic. The hierarchical structure of environmentally conscious design indices was constructed using the analytical hierarchy process (AHP), which include five aspects: i.e. energy, recycling, toxicity, cost, and material. After weighting factors for the environmental attributes are determined, the most desirable design alternative can be selected based on the fuzzy multi-attribute decision-making (FMADM) technique. The benefit of using such a technique is to effectively solve the design problem by capturing human expertise.

Carnahan and Thurston (1998) presented a decision tool in the form of a mathematical model; in order to optimize the design objectives when there are inevitable trade-offs among them. First, the framework of a multi-attribute utility function is developed to determine which objectives are both relevant and negotiable. Then, some of the constraints that prevent all objectives being maximized are formulized. Multi-attribute evaluation methods attempt to identify the best trade-off among conflicting attributes.

Green Pro (Khan et al., 2001) is a systematic methodology for process design that considers assessment and minimization of environmental impact. In order to identify a cost effective solution, this analysis considers environmental, technological and economic factors at the design stage. This tool applies Multi Criteria Decision Making analysis mainly. However, the assessment lacks in social aspects of sustainable approach. Moreover, boundary analysis is limited to “cradle to gate”

There are some other analysis tools available in the literature. Tischner et al. (2000) proposed ABC-Analysis tool that is useful for determining the environmental impacts of a product. This type of tool evaluates the product in terms of different criteria and classifies them as problematic, action required, medium, to be improved, harmless or no action required.

Some specific tools are used to compare different concepts of products. Philips Fast Five Awareness (Meinders, 1997) tool observes and compares different product concepts by using a reference product. It evaluates the products in terms of energy usage, recyclability, hazardous waste content, durability and service providing ways. Schmidt and Bleek propose the Funktionkosten tool that determines effective product alternatives in terms of cost to be developed and/or assesses changes of cost due to implementation of an environmental conscious design principle. Alternative solutions are evaluated on their costs of each function of the products that are described earlier. Dominance matrix (Byggeth and Hochschorner, 2006) is another comparison tool that aims to establish ranking for different criteria and solutions by carrying out a systematic comparison between the alternatives. There is a qualitative comparison among each individual alternative. Spiderweb (Tischner et al., 2000) is a tool that helps decision process between different design alternatives. A set of criteria is first defined for the estimation and then a qualitative evaluation of the criteria follows, giving an environmental profile for each solution eventually. EOD (Environmental Objectives Deployment) (Karlsson, 1997) shows the relationships between product’s technical description and environmental considerations. The environmental considerations are weighted and specified by the user.

There are also some other prescribing tools to mention a bit. Strategy List is a prescribing tool that aims to improve the environmental performance of a product concept or compare different types of product concepts. The tool involves list of suggestions based on some criteria for life cycle phases of the product in order to improve performance. Ten Golden Rule (Byggeth and Hochschorner, 2006) is a qualitative analysis method that provides common foundation to be used as a basis and guidelines for the development of specific product design. It is mainly a summary of many guidelines of the company and handbooks of different origins. Before using the tool in the company, the rules should be customized to specific company and its products. The tool is used for improvement of environmental performance of a product or comparison of different product concepts. As a difficulty, to apply this method, the designer must have background knowledge to make use of these rules effectively. The disadvantage is that the results of the analysis may differ due to designer knowledge and experience.

However, the methods available in the literature, are not good enough to support designers and there are few to help designers find solutions in DFE for variety of processes. That is to say, most of the current methodologies and tools serve in a fragmented way which limits designers in finding effective solutions to sustainability problems efficient

3.4.2. Main Differences in Approaches

In identifying the environmental aspects of a product system in order to make improvements ,there is no method that is preferable over all others under all applications (condition), since different types of information are needed depending on the purpose of the application

The type and depth of information needed is determined by the intention of the methods. It is wise to select the tools for "desing for environment " depending on the type and the depth of the information needed and the intention of the method.

The tools that are present in the literature, differ in many aspects. These aspects could be listed as follows:

- whether the information needed is quantitative or qualitative (the nature of input data)
- whether the tool is supporting holistic view of the product system
- whether it supports trade-off analysis and the level it supports the trade off (between different attributes of the product, between life cycle stages of the product, between environmental aspects and other "specific to business" aspects)
- the amount of information and time needed to conduct the study
- the accuracy level of the output

- ease of use
- whether it gives general or concrete prescription
- whether it involves valuation (rating the importance of criteria or strategies)
- and their purpose (analysis, providing assistance, comparison, prescribing, evaluation) (assessment of environmental impacts, identification of environmental critical aspects, comparison of environmental design strategies, comparison of product solutions and prescription of improvement strategies.)

In the next sections, first we mention the product design stage of application. A classification between holistic and focused view of the method/tool on products follows afterwards. Then we would analyze qualitative vs. quantitative nature of them briefly followed by concrete vs. general prescription. We would provide a table including tools with information about related categories and then map the important Ecodesign tools, placing them in a Design phase of application vs. Qualitative/Quantitative framework. As we would use above mentioned four classifications in our table and map later, here, we introduce them briefly.

3.4.2.1. Product Design Process Stage of Application

Tools differ due to design process phase they could be applied. Main design phases could be classified as: conceptual, embodiment and detailed design phases. As seen in the graph below, the earlier design phase of the product, the less knowledge about product whereas potential for improvement acts in contrast with this.

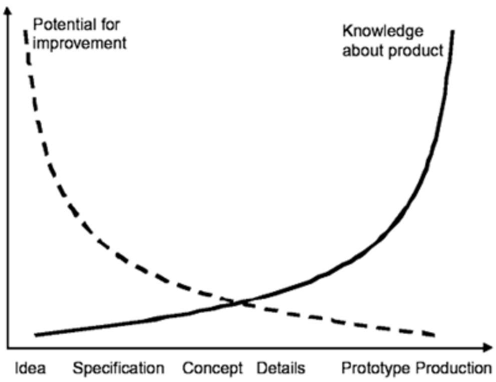


Figure 9: Knowledge- Environmental Performance vs. Design Phase (Hauschilda et al., 2004).

At the early idea- or conceptual stage, where the product is only loosely conceptualized, the possibilities for changes and hence for improvement of the environmental characteristics are large. If the goal is factor 10 improvements, this is clearly where the attention should be focused. During the early stages, a detailed and quantitative LCA is not relevant to perform, since the product is so loosely defined. Instead, more qualitative life cycle thinking or LCA of different product concepts and life scenarios are the tools to apply for analyzing environmental impacts and identifying potential environmental hot spots. Later in the product development process, it is possible to analyze consequences of small design changes. The improvement potentials are more modest here, but this is the situation for the frequent add- on oriented product development where a new version of the product largely is based on the existing version (Hauschilda et al., 2004).

3.4.2.2. Holistic vs. Focused Approaches

One of the vital perspectives to consider about tools/methods is to understand whether they employ a life cycle based approach or not. Those, taking life cycle perspective have a holistic view whereas others are focused.

Apart from the methodologies which inherit holistic character, there are many approaches focused on the single environmental aspect of a product. Design for ”X” methods are often structured to address only one specific problem that the address only one specific problem that designer previously did not consider and must be abandoned or significantly modified as new “X”s arise. DFX efforts each make an important contribution by providing methods for including “X” in the design process; however they do not directly address the trade-offs that must be made among various “X”s. Applying DFX tools does not necessarily guarantee that overall environmental impact of the product is better off. Focusing on one aspect may cause to lose sight over the other life-cycle phases (Carnahan and Thurston, 1998).

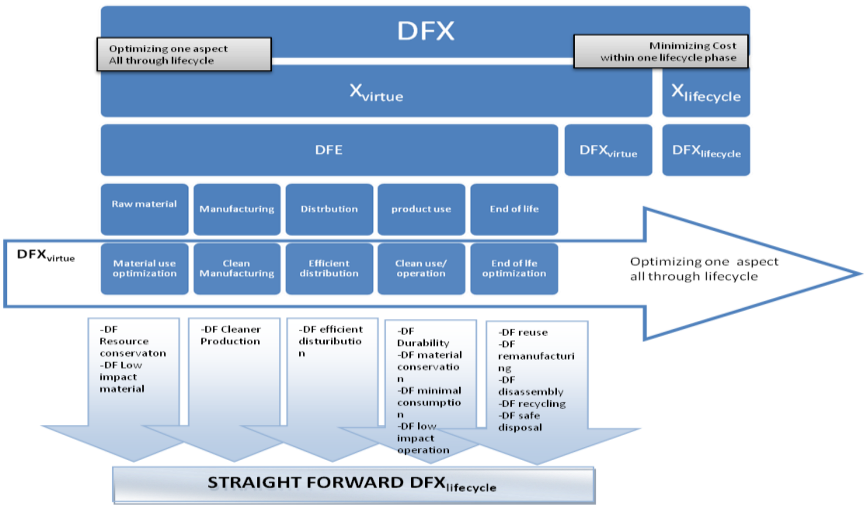


Figure 10: Classification of DFX

3.4.2.3. Qualitative vs. Quantitative Approaches

The tools have a qualitative or quantitative approach or both. The approaches are all useful and a combination of them can be preferred to facilitate a choice. A potential problem with qualitative results is that, most products may turn out to be rather similar. Many times it is the quantitative aspects that can differentiate between products (Hendrickson et al., 2005).

Qualitative approaches are mainly useful to identify critical aspects or problems. For example, all products that in their lifecycle use energy from combustion processes (i.e. most products) will cause emissions of heavy metals and persistent organic pollutants. i.e. how much energy is used and how large emissions of heavy metals and persistent organic pollutants are caused by the different products. Since the quantitative dimension is lacking in a purely qualitative evaluation, it may be difficult to differentiate between different products.

A general problem with qualitative analyses is how to compare different aspects. Life cycle assessments are comparative. The comparison is either with an alternative system, with a reference or internal within the analyzed system to identify important environmental aspects. The lack of a quantitative dimension hinders the comparison and can thereby hinder the usefulness of the qualitative method (Hochschorner and Finnyeden, 2003). However, quantitative methods are more objective but on the other hand more time consuming.

3.4.2.4. General / Concrete Prescription

Tools can be classified due to the prescription provided. Some tools give concrete (detailed and informative) prescription of which environmental aspects to consider whereas some others that give general prescriptions do not give information about environmental aspects to consider, thus the designer has to decide aspects to take into account.

This dimension of classification is analyzed in this study as it is useful to determine also easiness of use. Tools with concrete prescriptions use a language understood by the users and enable them to quickly identify appropriate ecodesign measures for the improvement of a product, whereas it is hard to implement immediately if tool provides general prescription.

3.4.2.5. Level of Need of Expertise

The tools differ also in terms of the need of expertise level. Assessments of some tools require a good environmental background whereas others could be easily understood without any background knowledge. We analyze here the ecodesign tools for the required level of expertise in three categories: i.e. low, medium and high levels of need of expertise and place the ecodesign tools mentioned in the article in one of these categories.

3.4.3. Consolidated Results on Main Differences

In the first table here, we classify prevalent Ecodesign tools that could be applied in obtaining sustainability objectives in product design according to three different differentiating areas. Whether they have qualitative or quantitative approach; whether a life cycle approach is considered or not and whether it gives concrete or general prescriptions about which environmental aspects to consider. Table below is a compilation of these mentioned above.

Tool	Life cycle approach	Qualitative/ Quantitative approach	General/ Concrete Prescription	Level of Need of expertise
Full LCA	yes	Quantitative	Concrete	High
GQFD-II	yes	Semi quantitative	Concrete	Medium
Eco-Design Guidelines	may be	Qualitative	Concrete	Low
ECO-DESIGN PILOT	yes	Qualitative	Concrete	Low
QFD-E	may be	Semi quantitative	Concrete	Medium
EIM	yes	Quantitative	Concrete	Low
Environmental Effect Analysis (EEA)	yes	Qualitative	Concrete	Medium
LIDS-Wheel	yes	Qualitative	Concrete	Low
Streamlined LCA	yes	Quantitative	Concrete	High
MECO Method	yes	qnt data need; results mixed	Concrete	High
MET Matrix	yes	mixed	General	High
Matrix approaches	yes	Semi quantitative/qualitative	General	Medium
Eco-Design Checklist	yes	Qualitative	Concrete	Low
DFX	no	Quantitative	Concrete	Medium
PDM (Prod. Design Matrix)	yes	Semi quantitative	General	Low

Table 1: Differences in approach for prevalent Ecodesign tools

Then, we built a map of general methodologies and prevalent tools used in sustainable product design. Figure below is shown the map of these prevalent tools, placing Product Design Phases in X and Quantitative/Qualitative nature of tool in Y axis.

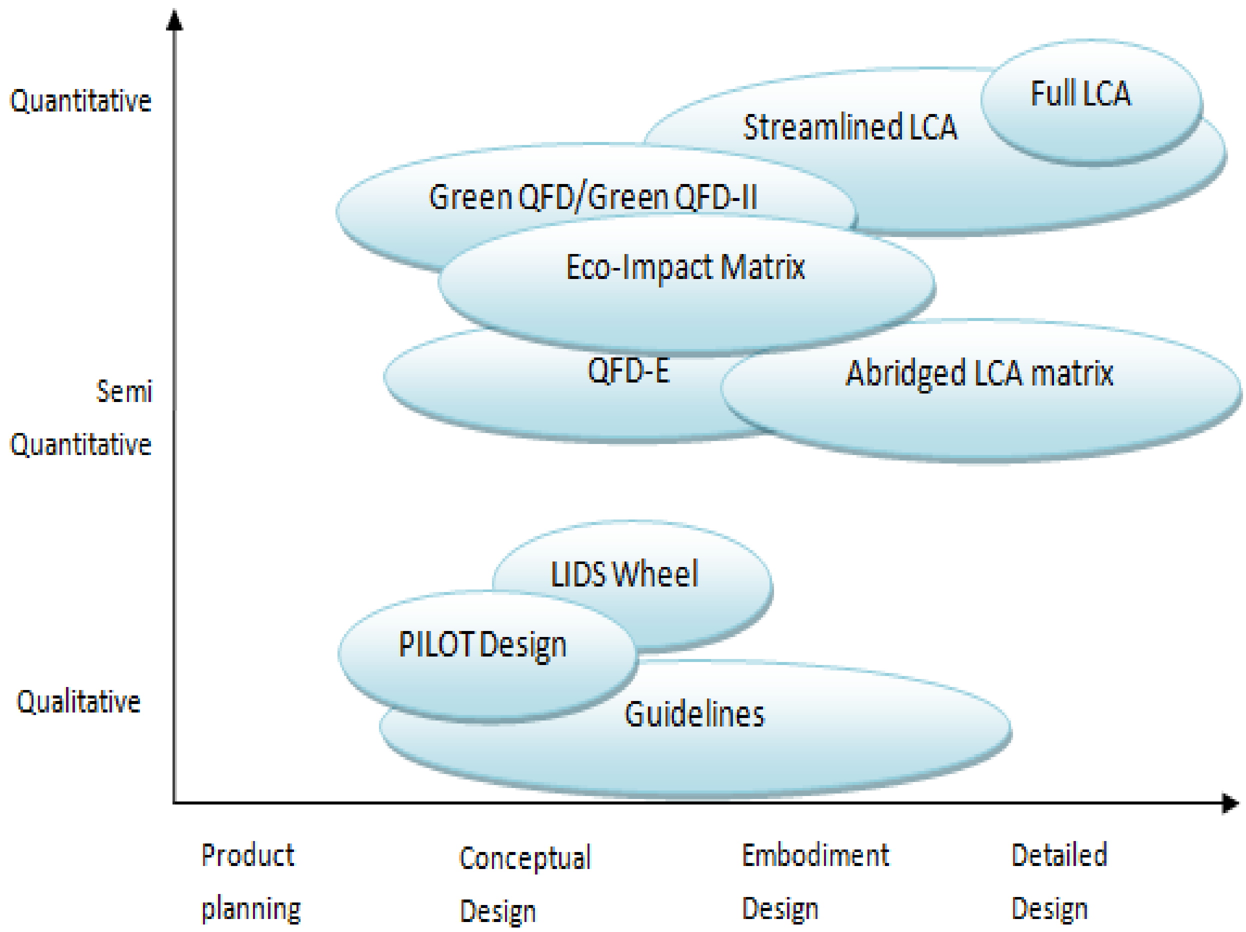


Figure 11: A map of Ecodesign tools: Product design phase – quantitative/qualitative nature space

In the table below we mention the advantages and disadvantages of some prevalent ecodesign tools in order to have a clear opinion about the conditions they would be used effectively.

Tool	Advantages	Disadvantages
Full LCA	• Involves a holistic approach. • Expands the debate on environmental concerns beyond a single issue, and attempts to address a broad range of environmental issues, by using a quantitative methodology, providing an objective basis for decision making.	• Data gathering is difficult as many of the life cycle stages involve proprietary processes. • Addresses potential rather than actual impacts. • Not suitable for early design

Guidelines/ Checklists	• Easiest way in introducing environmental issues in design (Bras, 1997).	• Due to their qualitative nature, hinder the assessment of trade-offs in particular. • reduce creativity, encouraging a false sense of complacency.
Lids Wheel	• Stimulate the creative design process. • Assist in visualizing current environmental performance. • Highlight opportunities for improvement. • Provides a basic framework that can be used systematically to review the entire life cycle of a product.	• Cannot be used to determine the actual environmental impact of a product, as it is a relative examination. • Inherently qualitative, and based on an arbitrarily defined system of evaluation, it is not a method that can be used to determine the actual environmental impact of a product (Brezet and Hemel,1997)
Abridged LCA Matrices (MET, ERPA, MECO)	• Identify critical aspects of a product. • Consider all the life cycle phases. • Fast, qualitative or semi quantitative methods to find the environmental impact from the life cycle of a product. • Complement a quantitative LCA study (Hochschorner and Finnyeden,2003).	• The assessment is subjective • All the characteristics for evaluations are given same amount of weight. • The subjective nature of the evaluations will cause some value judgments and the accuracy of the assessment is dependent on the expertise and knowledge of the assessor(s). • It does not take cost considerations into account
GQFD-II	• can be used for evaluating the different product concepts with respect to quality, environment and cost. • takes a life cycle approach that avoids substituting one set of problems for a different set of problems. • Various requirements can be prioritized, that is a guide for product development teams to focus their limited resources.	• GQFD-II depends on a detailed and time consuming LCA (Life Cycle Analysis) that requires designers to have a comprehensive understanding of environmental science. • Product comparisons made using GQFD-II rely on a complex decision making algorithm that lacks a coherent quantitative basis (Wang and Mehta, 2001).

Table 2: Advantages and limitations of ecodesign tools

4. METHODOLOGY

This chapter aims at providing an overview of the objectives of the research and the design of the methodological approaches used.

To achieve the objectives mentioned in the second chapter; an on-line survey and 3 case studies had been carried out. An on-line questionnaire has been proposed to over 200 contacts, of which only 10 companies replied directly via the link provided to them by mail. In order to increase the relevance of the entire work, further 3 case studies including face to face interviews and analyzing the internal documents had been done. Internal documents were supplied by contacts in the companies. In fact, since the number of responses to the direct questionnaire was lower than expected, other companies, that implement sustainability in their product design processes, have been analyzed as case studies.

Some of the companies that replied the on-line survey include some well known companies such as COMAU, CENTRO RICERCA FIAT (CRF), BTICINO, EDISON and ARCELIK A.S. as well as some other relatively small companies. Besides, 3 companies selected for carrying out a case study were COMAU, PIRELLI and BRIDGESTONE, which include face to face interviews and analysis of the internal documents provided by our contacts in mentioned companies. In total, there are 10 responds to survey and 3 case studies as explained above.

Aligned with the aim of this paper, a questionnaire has been developed and used as a tool for analyzing the companies that we thought they might have already been integrating sustainability into their product design processes for several years.

The main objective of this questionnaire was to understand how and what companies are doing currently to integrate sustainability into their products and product design processes. With the help of the survey, we intended to identify the gap between the literature and the practice. The results of the survey would be used to develop a modified or a new method of integrating sustainability criterions into the product development processes that fill the existing gap.

This survey was composed of questions about company characteristics, sustainable strategies and applications of the company, ecodesign tools and relevant product development processes in order to find an answer to above questions.

The questionnaire has been approved after some revision phases in which some of the questions have been modified in order to simplify their understanding, and other questions have been added, in order to gain all the possible information aligned with our objectives. The expected recipients of the questionnaire were product development department responsible. The research began by sending the questionnaire by email to all the contacts collected and resending if not replied.

These are the respondents to our on-line survey:

COMAU	EDISON	bticino
CRF CENTRO RICERCHE FIAT	arçelik	FontanaPietro A FontanaGroup Company
lampregroup lamiere preverniciate	CAREL	ABB

The final vision of the on-line questionnaire is exhibited in the *Appendix* of this paper.

Because of the inadequate number of responses to our on-line survey, we decided to have another instrument in order to realize our aims of the thesis and we carried out 3 case studies. We tried to collect relevant information about sustainability practices and sustainable product design processes of the companies via face to face interviews and analysis of their internal documents. In the case of COMAU, a face to face interview has been made with advanced engineering director and technical responsible. As most of the companies support their sustainability program by including in each Annual Report the Sustainability Program of the coming year, in order to underline the importance covered by sustainability within the corporate strategy of the entire company, we had a look at these types of documents for concerning companies as well.

These are the companies for the case studies:

COMAU	PIRELLI	BRIDGESTONE

5. RESULTS

5.1. Survey Results Analysis

The survey was composed of questions about company characteristics, sustainable strategies and applications of the company, ecodesign tools and relevant product development processes. It consists of 26 questions in total, 2 of which are optional. In this chapter we will try to analyze the responds given to these questions one by one first and then a more comprehensive, general idea.

5.1.1. Analysis of the Survey Questions

Ecodesign Product Survey_Politecnico Di Milano_Dep. of Management, Economics and Industrial Eng. SurveyMonkey

1. What is the name of the Company and which sector does the company serve?

	Response Count
	10

The first question was an introductory one to know the names and sectors of the companies. The respondents to survey include companies mainly from Electronic and Electro-technical products, Automotive, Energy and household appliances sectors.

Here is the list of the companies that respond to survey:

COMAU	EDISON	bticino
CRF CENTRO RICERCHE FIAT	arçelik	FontanaPietro A FontanaGroup Company
lampregroup	CAREL	ABB

2. Do you consider sustainability approach in your product development processes?

	Response Percent	Response Count
Yes	90.0%	9
No	10.0%	1

In the beginning of the process, we sent the questionnaire to the companies that we thought they might have already been integrating sustainability into their product design processes for several years or at least they should have been implementing. As a result 90% of the companies that replied to survey told that they considered sustainability approach in their product development processes.

3. How would you define briefly your sustainable product strategy?

Below, there are some sample answers about companies' sustainable product strategies:

"The company strategy aims at offering solutions to support end-user customers to achieve the environmental targets established by European governance in terms of innovative products for new plants and re-design of existing production lines".

"Ecodesign of the products assisted by Life Cycle Assessment and integrated in our environmental management system".

"Foreseen the customer demands"

"Product design and development are compliant with a global sustainability approach, aimed to:

- Reduce CO2 and polluting emissions
- Increase recoverability, recyclability and reusability of vehicle
- Continue to improve product safety".

"To be the best environmental company".

4. What is the level of investment on sustainable products compared to R&D costs?

	Response Percent	Response Count
N/A	33.3%	3
<5%	11.1%	1
5-10%	33.3%	3
10-25%	11.1%	1
25-40%	0.0%	0
More than 40%	11.1%	1

This is to have a general idea about the importance given to sustainable product design practices in companies. As seen from the above graphs, the level of investments of companies is mostly at low levels or even not available. The companies do not invest enough in sustainable practices. Their investments are mostly around 5-10 % of their R&D costs which would be considered as very low.

5. Which environmental regulations/policies does the company concern?

	Response Percent	Response Count
RoHS (Restriction of Hazardous Substances)	70.0%	7
WEEE (Waste Electrical and Electronic Equipment)	40.0%	4
REACH (Registration, Evaluation, Authorisation and Restriction of Chemical substances)	**80.0%**	**8**
ELV (End of life vehicles)	20.0%	2
IMDS (International Material Data System)	20.0%	2
EuP (eco-design requirements for energy-using products)	20.0%	2
Packaging regulation	20.0%	2
ISO 14001 Certified Environmental Management System	70.0%	7
EH&S Policy (Environment, Health and Safety Policy)	60.0%	6
Other (please specify)	20.0%	2

This question was about the environmental regulations/policies that companies concern. The aim here is to understand what sort of voluntary (e.g. ISO 14001 and others) and mandatory [e.g. WEEE (electric/electronics), ELV (for automotives), RoHS, REACH …] policies companies adopt in practices.

As seen from the responds, REACH takes the lead as 8 of 10 respondents adopt it. Then follow RoHS and ISO 14001 Environmental Management System.

6. Please estimate as a percentage the dependence of the company's sustainability related decisions on the following 3 pillars of sustainability? (Sum of all choices should be 100)

		Response Average	Response Total	Response Count
Economic aspects		47.00	423	9
Environmental aspects		30.89	278	9
Social aspects		22.11	199	9

It is unlikely that a company will make a choice that is not primarily economically driven. Furthermore, it is of crucial importance that new products meet market requirements. Therefore, there is a risk that the environment will not be the highest priority in some trade-off situations (Hochschorner and Byggeth, 2005). We aim to determine the main decision variable for companies' applications with this question. It is helpful in determining whether the environment is of major concern also.

As expected, for companies the priority is economic aspects, then environmental and social aspects follow respectively. As they respond, almost 50% importance for the decisions is on economical aspects. Especially, in real practices we observe that the decisions are even more economic driven than the results here.

7. Regarding your product range, how would you rate the severity of the adverse environmental impacts observed in the following life-cycle stages?

	Severe	Moderate	Slight	None	Response Count
Material Acquisition	**40.0% (4)**	**40.0% (4)**	0.0% (0)	20.0% (2)	10
Manufacturing	**50.0% (5)**	20.0% (2)	20.0% (2)	10.0% (1)	10
Distribution	11.1% (1)	22.2% (2)	**33.3% (3)**	**33.3% (3)**	9
Use	20.0% (2)	**50.0% (5)**	10.0% (1)	20.0% (2)	10
End of life	**50.0% (5)**	20.0% (2)	20.0% (2)	10.0% (1)	10

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. We intended to classify lifecycle stages due to their impacts on environment based on feedback from the companies.

As understood from the answers above, companies observe the most environmental impact in manufacturing and end of life phases for the products. Then, material acquisition phase has also important impact. Use phase's impact on environment is relatively lower whereas distribution phase has a very slight effect on nature.

8. Which environmental parameters are used for evaluating environmental aspects in your product design?

	Response Percent	Response Count
Hazardous Substances	77.8%	7
Raw Material and Energy Consumption	**88.9%**	**8**
Recycling and Disposal	77.8%	7
Packaging (recyclable material)	33.3%	3
Waste Minimization	66.7%	6
Material Recovery	22.2%	2
Energy Efficiency	**88.9%**	**8**
Source Reduction	33.3%	3
Material Content	55.6%	5
Water Consumption	22.2%	2
Toxic Dispersion	22.2%	2
Use of renewable resources	22.2%	2
Product Durability	55.6%	5

To identify the mostly used environmental parameters for evaluating environmental aspects in product design is important to have an idea about the focus of the companies during their sustainable practices. As obvious from the responds above, raw material & energy consumption and energy efficiency are the most important parameters considered by companies. Hazardous substances, recycling &disposal and waste minimization are other important factors. For the companies, energy related parameters have significant importance and play a major role in their decisions.

9. How would you rate the company's consideration of following factors during product design?

	Not important	Somewhat important	Important	Very important	Response Count
Cost	0.0% (0)	0.0% (0)	10.0% (1)	**90.0% (9)**	10
Quality	0.0% (0)	0.0% (0)	0.0% (0)	**100.0% (10)**	10
Function	0.0% (0)	0.0% (0)	30.0% (3)	**70.0% (7)**	10
Ergonomics	10.0% (1)	**40.0% (4)**	10.0% (1)	**40.0% (4)**	10
Safety	11.1% (1)	0.0% (0)	11.1% (1)	**77.8% (7)**	9
Environmental aspects	10.0% (1)	**30.0% (3)**	**30.0% (3)**	**30.0% (3)**	10
Legal requirements	0.0% (0)	20.0% (2)	**40.0% (4)**	**40.0% (4)**	10

During product design, there are several factors that concern companies. However, some of them are more important compared to others. 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. In order to identify the importance of these factors for the companies and to see where environmental consideration stands among these, we came up with this question.

As understood from the companies' responds quality and cost seem to be the most important factors considered during product design. As seen, environmental aspects and legal requirements are not the priority ones for the companies. They are still not forcing factors for companies.

10. How would you rate the importance of the following driving factors for the company to implement ecodesign?					
	Not important	Somewhat important	Important	Very important	Response Count
Improving resource and process efficiency	10.0% (1)	10.0% (1)	20.0% (2)	**60.0% (6)**	10
Potential Product differentiation	0.0% (0)	**60.0% (6)**	10.0% (1)	30.0% (3)	10
Cost saving	10.0% (1)	10.0% (1)	30.0% (3)	**50.0% (5)**	10
Reduction in regulatory burden and potential liability	11.1% (1)	**44.4% (4)**	33.3% (3)	11.1% (1)	9
Customer demand	0.0% (0)	20.0% (2)	**50.0% (5)**	30.0% (3)	10
Competitors' activities	10.0% (1)	20.0% (2)	**50.0% (5)**	20.0% (2)	10
				answered question	10

When we look at the driving factors for the companies to implement ecodesign (factors that push companies in ecodesign practices), we see that "improving resource and process efficiency" and "cost saving" are significantly considerable driving factors for them. "Customer demand" follows these driving factors.

11. How would you rate the following internal stimuli (reasons why ecodesign option is interesting, regardless of the influence of external parties) regarding your company's sustainable product design?					
	Mostly	Sometimes	Rarely	Never	Response Count
The company expects a reduction of the environmental impact (commitment to reduce the environmental impact)	**70.0% (7)**	10.0% (1)	10.0% (1)	10.0% (1)	10
The company expects a reduction of costs (lower cost-price of the product)	**60.0% (6)**	10.0% (1)	20.0% (2)	10.0% (1)	10
The company expects an image improvement (leading to competitive advantage)	**60.0% (6)**	30.0% (3)	0.0% (0)	10.0% (1)	10
The company expects new market opportunities (competitive advantage: increasing actual market share/access to new markets)	**60.0% (6)**	30.0% (3)	10.0% (1)	0.0% (0)	10
The company expects an increase of the product's functional quality	10.0% (1)	**60.0% (6)**	30.0% (3)	0.0% (0)	10
The company perceives another internal stimulus	10.0% (1)	**50.0% (5)**	30.0% (3)	10.0% (1)	10
The company expects a synergy with product requirements other than functional quality demands or low costs	**30.0% (3)**	20.0% (2)	**30.0% (3)**	20.0% (2)	10
The company expects a commercial benefit, other than those mentioned in previous (e.g. synergy with care systems, risk reduction, increased efficiency in production, storage, distribution, etc.)	**60.0% (6)**	30.0% (3)	10.0% (1)	0.0% (0)	10
The company regards the option as an interesting long-term innovation opportunity	**70.0% (7)**	20.0% (2)	10.0% (1)	0.0% (0)	10

In this question, we asked the companies to rate the internal stimuli (reasons why ecodesign option is interesting, regardless of the influence of external parties) provided them as a list regarding their company's sustainable product design. The most referred internal stimuli were "The Company regards the option as an interesting long-term innovation opportunity" and "The Company expects a reduction of the environmental impact (commitment to reduce the environmental impact)". Image improvement, reduction of costs and new market opportunities are other reasons for the companies to find ecodesign interesting. As seen, companies mostly think ecodesign as achieving long term objectives. Besides, if to do a comment the companies' respond as their commitment to reduce environmental impact here might not reflect the reality as they tend to show/think their companies more committed than they actually are. In reality, most of the decisions and interest depend on either costs or long term plans as image improvement and entering to new markets.

12. What kind of barriers you face standing in the way of the suggested ecodesign improvement options and how often?

	Mostly	Sometimes	Rarely	Never	Response Count
Doubt about the environmental benefit of the option suggested	10.0% (1)	**50.0% (5)**	20.0% (2)	20.0% (2)	10
The company does not feel responsible for realizing the option	10.0% (1)	10.0% (1)	**60.0% (6)**	20.0% (2)	10
The option only becomes relevant if supported by environmental legislation	30.0% (3)	**60.0% (6)**	10.0% (1)	0.0% (0)	10
The option creates a commercial disadvantage for the company	0.0% (0)	30.0% (3)	**60.0% (6)**	10.0% (1)	10
The option creates a conflict in connection with actual functional product requirements	0.0% (0)	**60.0% (6)**	30.0% (3)	10.0% (1)	10
The option is not a challenging echnological innovation opportunity for our company	0.0% (0)	**40.0% (4)**	**40.0% (4)**	20.0% (2)	10
Realization depends on available technical possibilities; at the moment there is no proper alternative	0.0% (0)	**70.0% (7)**	20.0% (2)	10.0% (1)	10
The company regards new investments in redesigning the product in question as fruitless	10.0% (1)	**60.0% (6)**	20.0% (2)	10.0% (1)	10
The company lack sufficient time to realize the option in question	**50.0% (5)**	0.0% (0)	30.0% (3)	20.0% (2)	10
The company perceives another type of barrier	0.0% (0)	**55.6% (5)**	33.3% (3)	11.1% (1)	9

In this question, we tried to identify the barriers companies face standing in their way of ecodesign improvement options by providing them a list of answers mostly referred in the literature and others choice as an option. Most of the companies mentioned the choices “The company lack sufficient time to realize the option in question” and “The option only becomes relevant if supported by environmental legislation” as the main barriers. “The company regards new investments in redesigning the product in question as fruitless” and “Doubt about the environmental benefit of the option suggested” are the other mentioned barriers.

13. What kind of benefits do you expect to get by applying eco-design?

	Response Percent	Response Count
Cost saving	60.0%	6
Stimulation of innovation	80.0%	8
New Business Opportunities	80.0%	8
Improved Product Quality	40.0%	4
Improved resource and process efficiency	60.0%	6
Increased market share	60.0%	6
Enhancement of the image of the product	90.0%	9
Enhancement of the image of the company	**100.0%**	**10**
Stronger competitive advantage	50.0%	5
Preservation of crucial resources	30.0%	3
Increased productivity and quality	30.0%	3
Stronger sales and customer loyalty	30.0%	3

More organizations are coming to realize that there are substantial benefits in integrating environmental aspects into product design and development. As seen from the responds above, “enhancement of the image of the company” is expected by all the companies involved in the survey. “Enhancement of the image of the product”, “Stimulation of innovation” and “New business opportunities” are other mostly expected benefits for the companies when applying ecodesign.

14. Do you use any ecodesign tools in your product design processes?

	Response Percent	Response Count
Yes	60.0%	6
No	40.0%	4

As seen above, 60% of the respondents use ecodesign tools somehow in their design processes whereas 40% of them do not use any ecodesign tools. The usage of ecodesign tools is still not prevalent in the industry. Even though these are selected companies for applying sustainability in their design processes for several years, the implementation of ecodesign tools is not common.

15. For how long have you been adopting ecodesign tools?

	Response Percent	Response Count
N/A	28.6%	2
Less than 1 year	0.0%	0
From 1 to 5 year	14.3%	1
From 5 to 10 years	28.6%	2
More than 10 years	28.6%	2

The companies adopting ecodesign tools implement this mostly more than 5 years. It is not surprising when we take into account that when choosing the companies we tried to choose the companies that might/should have been implementing these kinds of practices for several years. However, if we look at the overall picture in the industries, obviously it is expected to be much lower than these periods.

16. Which ecodesign tools are used in company's practices? How would you rate the frequency of use and Effectiveness of concerning tools?

	Never	Sometimes	Always	Not Effective	Somewhat Effective	Very Effective	Response Count
LCA-based (Full LCA, Streamlined LCA, etc...)	14.3% (1)	28.6% (2)	28.6% (2)	14.3% (1)	14.3% (1)	**57.1% (4)**	7
QFD-based (EQFD, GQFD, etc...)	16.7% (1)	**66.7% (4)**	16.7% (1)	16.7% (1)	50.0% (3)	16.7% (1)	6
Checklist-based	0.0% (0)	**57.1% (4)**	28.6% (2)	14.3% (1)	**57.1% (4)**	14.3% (1)	7
Strategy-Wheel	**66.7% (4)**	16.7% (1)	16.7% (1)	16.7% (1)	16.7% (1)	0.0% (0)	6
Environmental Effect Analysis (EEA)	**83.3% (5)**	16.7% (1)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	6
Matrix Based	**83.3% (5)**	16.7% (1)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)	6
Design for Recycling	14.3% (1)	**71.4% (5)**	14.3% (1)	14.3% (1)	42.9% (3)	14.3% (1)	7
Design for Safe Disposal	**57.1% (4)**	42.9% (3)	0.0% (0)	0.0% (0)	14.3% (1)	0.0% (0)	7
Design for Disassembly	**57.1% (4)**	28.6% (2)	14.3% (1)	0.0% (0)	14.3% (1)	14.3% (1)	7
Design for Remanufacturing	**57.1% (4)**	28.6% (2)	0.0% (0)	0.0% (0)	14.3% (1)	14.3% (1)	7

Many eco-design tools and methods exist: some are extremely simple and qualitative, while others are complex and quantitative. The selection of the best tool for a given application depends on the individual situation of the context of the design and development process.

Having a look at the responds from the companies, it is not hard to see that they do not use most of the types of ecodesign tools. Mostly used ecodesign tool seems to be LCA. One reason for that would be that LCA is a tool that is recognized by regulators, legislators, scientists, consumer groups and environmental groups alike, and so it represents a common basis for the environmental quality assessment of products and processes (Hendrickson et al., 2005). Also, Small Medium Sized Enterprises (SMEs) that use LCA will have several advantages over their competitors. They will be able to identify opportunities for waste reduction that will lead to a continuous improvement of their products and processes.

Besides LCA, QFD based and checklist based tools together with design for recycling applications are other prevalent tools used in companies' practices. Most of the other tools present in the literature are not used and even sometimes not recognized by companies. There is a huge gap here between literature and the applications of companies.

17. How would you rate the importance of the following criteria when choosing the suitable ecodesign tool in your company?

	Not important	Somewhat important	Important	Very important	Response Count
Easy to learn	0.0% (0)	0.0% (0)	**85.7% (6)**	14.3% (1)	7
Easy to implement	0.0% (0)	0.0% (0)	28.6% (2)	**71.4% (5)**	7
Deliver fast results	14.3% (1)	0.0% (0)	**71.4% (5)**	14.3% (1)	7
Deliver accurate results	0.0% (0)	0.0% (0)	**71.4% (5)**	28.6% (2)	7
The amount of required information	0.0% (0)	14.3% (1)	**57.1% (4)**	28.6% (2)	7
Comprehensive (life cycle stages / impacts)	0.0% (0)	**57.1% (4)**	42.9% (3)	0.0% (0)	7
Less data intensive	0.0% (0)	42.9% (3)	**57.1% (4)**	0.0% (0)	7
Deliver simple results	0.0% (0)	28.6% (2)	**42.9% (3)**	28.6% (2)	7
Availability of resources for the assessment	0.0% (0)	14.3% (1)	**71.4% (5)**	14.3% (1)	7

The tools differ in many aspects and companies have criteria when choosing the appropriate tool. As seen above, the most important criteria for them are that they want tools that are "easy to implement" and "easy to learn". "Delivering accurate results", "the amount of required information" and "availability of resources for the assessment" are the other important criteria referred by companies.

18. Is there any mechanism to use the output of the previous ecodesign projects to improve the accuracy of the ecodesign tools?

	Response Percent	Response Count
No	**57.1%**	4
Yes	42.9%	3

Regarding the mechanisms about using the outputs of previous ecodesign projects to improve the accuracy of the ecodesign tools or processes, only 3 companies told they have such mechanisms. Below is how they do it:

"Sometimes the design tools are developed together with the tools suppliers"

"Up-dating historical databases"

"If we use qualitative ecodesign tools (like checklist tools) it is important to verify results with quantitative ecodesign tools (LCA-based tools)".

19. Do you make any simplifications during environmental assessment of the product? If yes, how would you rate the frequency of use of the following simplified approaches in the following table?

	Never	Rarely	Sometimes	Usually	Always	Response Count
All processes prior to final materials manufacturing are excluded	12.5% (1)	**62.5% (5)**	0.0% (0)	25.0% (2)	0.0% (0)	8
All processes after final materials manufacturing excluded	**57.1% (4)**	14.3% (1)	14.3% (1)	14.3% (1)	0.0% (0)	7
Only primary materials manufacturing is included, as well as any pre-combustion processes for fuels used in manufacturing	**57.1% (4)**	14.3% (1)	14.3% (1)	14.3% (1)	0.0% (0)	7
Selected entries are used to approximate results in all impact categories, based on mass and subjunctive decisions; Other entries within each category are excluded	**85.7% (6)**	0.0% (0)	0.0% (0)	14.3% (1)	0.0% (0)	7
Using qualitative or less accurate data	0.0% (0)	12.5% (1)	25.0% (2)	**62.5% (5)**	0.0% (0)	8
Selected processes are replaced with apparently similar processes based on physical, chemical, or functional similarity to the database being replaced	33.3% (2)	0.0% (0)	**50.0% (3)**	0.0% (0)	16.7% (1)	6

About the simplifications carried out during environmental assessment of the product, there are 2 dominant options that would be highlighted depending on the results of the survey. The companies mostly refer to "Using qualitative or less accurate data" and "Selected processes are replaced with apparently similar processes based on physical, chemical, or functional similarity to the database being replaced".

20. If you ever faced a failure during your eco-design projects, what was the main cause for it?

	Mostly	Sometimes	Rarely	Never	Response Count
Lack of knowledge about environmental issues on the part of people involved	**37.5% (3)**	25.0% (2)	12.5% (1)	25.0% (2)	8
Existence of too many uncertainties	0.0% (0)	**75.0% (6)**	0.0% (0)	25.0% (2)	8
Lack of understanding regarding the impact of ecodesign on areas such as regulation, cost reduction, competitive advantage and organizational image improvement	0.0% (0)	**37.5% (3)**	**37.5% (3)**	25.0% (2)	8
Lack of consensus about how to evaluate products in environmental terms	12.5% (1)	**50.0% (4)**	12.5% (1)	25.0% (2)	8
Lack of relevant standards	0.0% (0)	**71.4% (5)**	14.3% (1)	14.3% (1)	7
The belief that environmental goals are necessarily at odds with economic objectives	0.0% (0)	**50.0% (4)**	25.0% (2)	25.0% (2)	8

Regarding the causes of failures during ecodesign projects, there is no dominant respond to others. However, "Lack of knowledge about environmental issues on the part of people involved" is more skewed to "mostly" part of the frequency and "Existence of too many uncertainties" has a relatively higher frequency than others.

21. How frequently are ecodesign tools used in above mentioned NPD process phases in the company?

	Never	Rarely	Sometimes	Usually	Always	Response Count
Product planning	44.4% (4)	0.0% (0)	0.0% (0)	0.0% (0)	**55.6% (5)**	9
Conceptual design	**44.4% (4)**	11.1% (1)	11.1% (1)	11.1% (1)	22.2% (2)	9
Embodiment design	33.3% (3)	0.0% (0)	0.0% (0)	**55.6% (5)**	11.1% (1)	9
Testing and prototyping	**33.3% (3)**	11.1% (1)	11.1% (1)	22.2% (2)	22.2% (2)	9

PRODUCT PLANNING	CONCEPTUAL DESIGN	EMBODIMENT DESIGN	TESTING AND PROTOTYPING
1- Description of the boundaries of the product's system 2- Identification of the entire environment related regulatory requisites 3- Market customers' requirements throughout the whole product life cycle	1- Analyzing the product's functions 2- Defining the target requirements of the product 3- Generating feasible solutions 4- Evaluating possible alternatives	1- Definition and dimensioning of a preliminary layout 2- Its assessment considering the whole life cycle 3- Detailed design of the new product	1- Assessing the constructive layout throughout the development of models and prototypes in order to complete the final verification and validation of the project

As seen from the responds, what is more right skewed are the product planning and embodiment design phases where companies use mostly ecodesign tools.

As, the primary task of the conceptual design phase is to satisfy the functional requirements, this phase, unlike all other phases that compose the design process, is also the one which is less supported by dedicated tools. Companies' responds also support this.

22. How would you compare ecodesign implementation to overall product development process of the company in terms of cost and time spent?

	Very Low	Low	Moderate	High	Very High	Response Count
COST	22.2% (2)	11.1% (1)	22.2% (2)	**44.4% (4)**	0.0% (0)	9
TIME	37.5% (3)	0.0% (0)	**62.5% (5)**	0.0% (0)	0.0% (0)	8

A competitive product must address cost and time-to-market. Cost and time is important factors that affect decision making and decisions in the companies consider these two dimensions. It is necessary to know the effects of ecodesign tools on time and cost as selection of the tool may depend on these constraints. As seen from the responds, for ecodesign they define cost as high and time as moderate compared to overall product development process.

23. Considering the four types of ecodesign stages in accordance with the degree of achieving eco-efficiency, which types are used in company's applications and how frequently?

	Never	Rarely	Sometimes	Usually	Always	Response Count
Product improvement (Type I)	11.1% (1)	0.0% (0)	**33.3% (3)**	22.2% (2)	**33.3% (3)**	9
Product redesign (Type II)	22.2% (2)	0.0% (0)	11.1% (1)	**66.7% (6)**	0.0% (0)	9
New product concept definition (Type III)	22.2% (2)	22.2% (2)	**33.3% (3)**	11.1% (1)	11.1% (1)	9
New product system definition (Type IV)	**44.4% (4)**	11.1% (1)	22.2% (2)	11.1% (1)	11.1% (1)	9

There are four types of ecodesign stages in accordance with the degree of achieving eco-efficiency (see figure). 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. Our aim is to figure out mostly applied ecodesign type in practices.

The 2 dominant types are "product improvement" and "product redesign" for ecodesign practices as expected.

24. Have you observed any significant internal changes in company practices after ecodesign implementation?

		Response Percent	Response Count
No		40.0%	2
Yes		**60.0%**	**3**

In many cases when environmental aspects are integrated in product development, it leads to synergies with other business interests, like image improvement, new market opportunities and sometimes cost reductions, even in the short term (Hochschorner and Byggeth, 2005). We need to understand if employed ecodesign/sustainability tools lead to internal changes in the company and to what extent is this impact. It is necessary to know the effects of ecodesign implementation on companies.

Only 3 companies told they had observed significant internal changes and defined them as below:

"New skill and competencies"

"If any good sales theme, the novelty is well appreciated"

"Overall increasing of the sensitivity on environmental topics"

25. What kind of obstacles you face when integrating sustainability in NPD processes? (Please list all or explain briefly)	
	Response Count
	2

As this question was open and optional, only 2 companies responded. The responds are:

"Higher cost of the end product or to develop a new technology; modifying existing machines to differently process the material, investment barrier".

"Introducing new approaches clashes with the typical resistance to change by engineering staff".

5.1.2. General Recap and Overview of the Responds

First of all, sustainability is not well integrated into product design yet. Companies' investments regarding this area are low compared to their R&D costs. There is still a long road for the companies on this sustainable way and there is a significant gap between literature and companies' practices.

Next, it is not likely that a company will make a choice that is not primarily economically driven. Furthermore, it is of crucial importance that new products meet market requirements. Therefore, there is a risk that the environment will not be the highest priority in some trade-off situations. The reason why companies mostly talk about or direct to environmental commitment is mostly a matter of marketing and advertisement. They try to enhance the image of the company and their products as well as looking forward to enter into new markets all of which could be considered as their long term objectives.

We see that the application of ecodesign tools and methods by SMEs are limited as mentioned in literature. It is not just because of the respondents' answers to survey but also many companies that should/might apply sustainability approach and ecodesign tools returned to our mails regarding the survey as either they are not interested in the concept or they really do not consider such approaches during their product design.

Despite the progressive use of ecodesign in the industrial world, taking into account environmental constraints remains problematical for small and medium sized enterprises (SMEs), which seem to be remaining on the fringe of the movement. Beyond the lack of environmental culture in the enterprises, the problem stems from the ecodesign tools which have not been designed with any thought of integrating them into the enterprises' organization.

Although a lot of ecodesign tools exist, environmental aspects are unfortunately rarely routinely integrated into product development process in the industry. This is mainly due to the fact that current ecodesign tools are little adapted to designers' practices, requirements and competencies.

5.2. Case Studies

5.2.1. COMAU Case

5.2.1.1. General Information about COMAU

COMAU is a global supplier of industrial automation systems and services mainly for the automotive manufacturing sector. Over the years, by acquiring and integrating other companies, COMAU broadened its presence all over the world, becoming the ideal partner for the automotive industry in developing solutions for all industrial production programs. The continuous improvement of products, processes and services, through the application of the most advanced innovative technological solutions, allows COMAU to contribute to its Customers' competitive advantage.

COMAU is a technology and innovation leader committed to the continuous improvement of products, processes and services, through the production of advanced manufacturing systems.

COMAU is organized into 3 Business Units: Body Welding & Assembly, Power train Machining & Assembly and Robotics & Service.

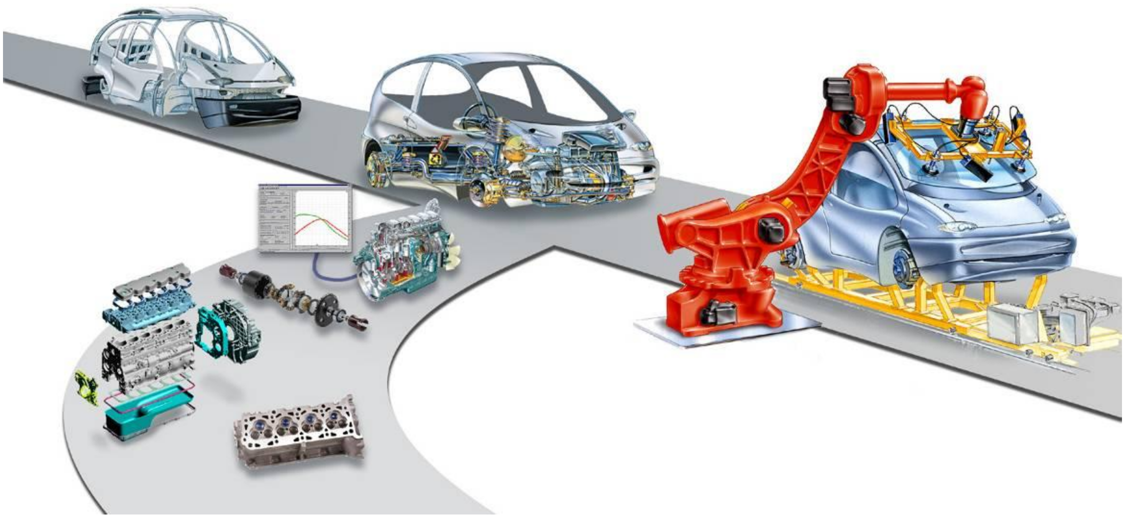


Figure 12: Representative Layout of a Line in COMAU

The company oversees its products from the idea and design phase, through to completion, training and maintenance. Products consistently exceed the needs and expectations of the customers in industry segments such as, automotive, aerospace, heavy industry, military, and recreational.

The offering of full service, from product engineering to production systems and maintenance services, together with a global organization, allows COMAU to compete in the continuously evolving market. COMAU provides integrated services to the manufacturing plants, from assistance to the production start-up phases, up to equipment and plant full maintenance activities.

COMAU is active in several industrial sectors, including automotive, aerospace, steel, petro-chemical and foundries.

With 26 locations in 15 countries, and more than 40 years of experience, COMAU takes pride in being a global leader in the industrial automation field, while providing the highest level of localized support.

5.2.1.2. Highlights from the Interview and Survey Responds

In the case study, COMAU Automotive S.p.a. is assessed including a visit to GRUGLIASCO Plant in Torino, Italy and face to face interviews with the advanced engineering director and technical responsible of the plant.

COMAU S.p.a. Automotive is a company serving in automotive sector and they consider sustainability in their product development processes since many years.

They define their sustainable product strategy briefly as "The company strategy aims at offer solutions to support end-user customers to achieving the environmental targets established by European governance in terms of innovative products for new plants and re-design of existing production lines".

They assume an investment at about 20% on sustainable products compared to their R&D expenses. Besides, they concern voluntary regulations such as ISO 14001 Certified Environmental Management System and EN16001. They are proud to be the 'First EN16001 Certified Italian Industrial Company'.

COMAU's advanced engineering director in their GRUGLIASCO Plant located in Torino, Italy mentions that almost all the decisions given depends on the economical aspects. Environmental aspects are not the priority if not supported by the strict regulations which do not occur until now in the industry, (he defines the current environmental regulations in the industry as slight and easy to apply for all the companies), as he says. He goes further to point out that the only reason that companies nowadays talk about environment is mostly about advertisement and marketing. However, what they apply in practice almost always depends on economic factors according to him.

For the automotive industry, there are severe environmental impacts related to material acquisition, use and end of life phases. In product design COMAU considers mostly Energy efficiency, Raw Material and Energy Consumption and Material Content as parameters. COMAU is mostly concerned with cost, quality and function during product design and environmental aspects are not the priority but just come after these factors together with legal requirements.

COMAU implements ecodesign mostly because of ‘improving resource and process efficiency’ and ‘customer demand’. By implementing ecodesign, the company expects a reduction of the environmental impact and an image improvement which could eventually lead to competitive advantage. The problem and the barriers standing on their way to implement ecodesign are those ‘the option only becomes relevant if supported by environmental legislation’ and ‘the company lacks sufficient time to realize the option in question’.

The benefits they expect are firstly enhancement of the image of the product and the company that could also lead to a stronger competitive advantage. They use ecodesign tools for several years which include LCA based, Checklist based tools and design for remanufacturing. They expect an ecodesign tool to have the following characteristics: ‘easy to learn’, ’easy to implement’ and ‘deliver simple results’. When they face a failure during ecodesign projects, it is mostly because of the ‘lack of knowledge about environmental issues on the part of people involved’.

What they mostly use ecodesign for is in product improvement and next for product redesign. After ecodesign implementation, the company realized an ‘Overall increasing of the sensitivity on environmental topics’ which they call as internal change. Finally, the introducing of new approaches clashing with the typical resistance to change by engineering staff is an obstacle for them when integrating sustainability in NPD processes.

5.2.1.3. EN 16001 Certification

On March 16, COMAU Italy became among the first European industrial companies to achieve EN16001:2009 Energy Management System certification, in compliance with the new European standard for energy efficiency issued on July 2009.

The program objectives have been met by a dedicated COMAU team and represent an initial step to extend Energy Efficiency programs and EN 16001 certification to all COMAU worldwide production site by the end of 2010.

Thanks to its Energy Efficiency program, COMAU has developed skills and technologies which have been immediately applied in its line of ECO friendly products and has matured experience and knowledge to play a leader role as *'GreenFit'* Service provider.

Service offering will range from consultancy in energy saving and ECO compatibility assessments, to implementation services for energy reduction and environmentally friendly activities. Products and Services are available now through the COMAU worldwide commercial network.

5.2.1.4. Sustainability Main Targets for COMAU

COMAU gives significant importance to sustainability practices. Below there is the figure representing COMAU's sustainability main targets.

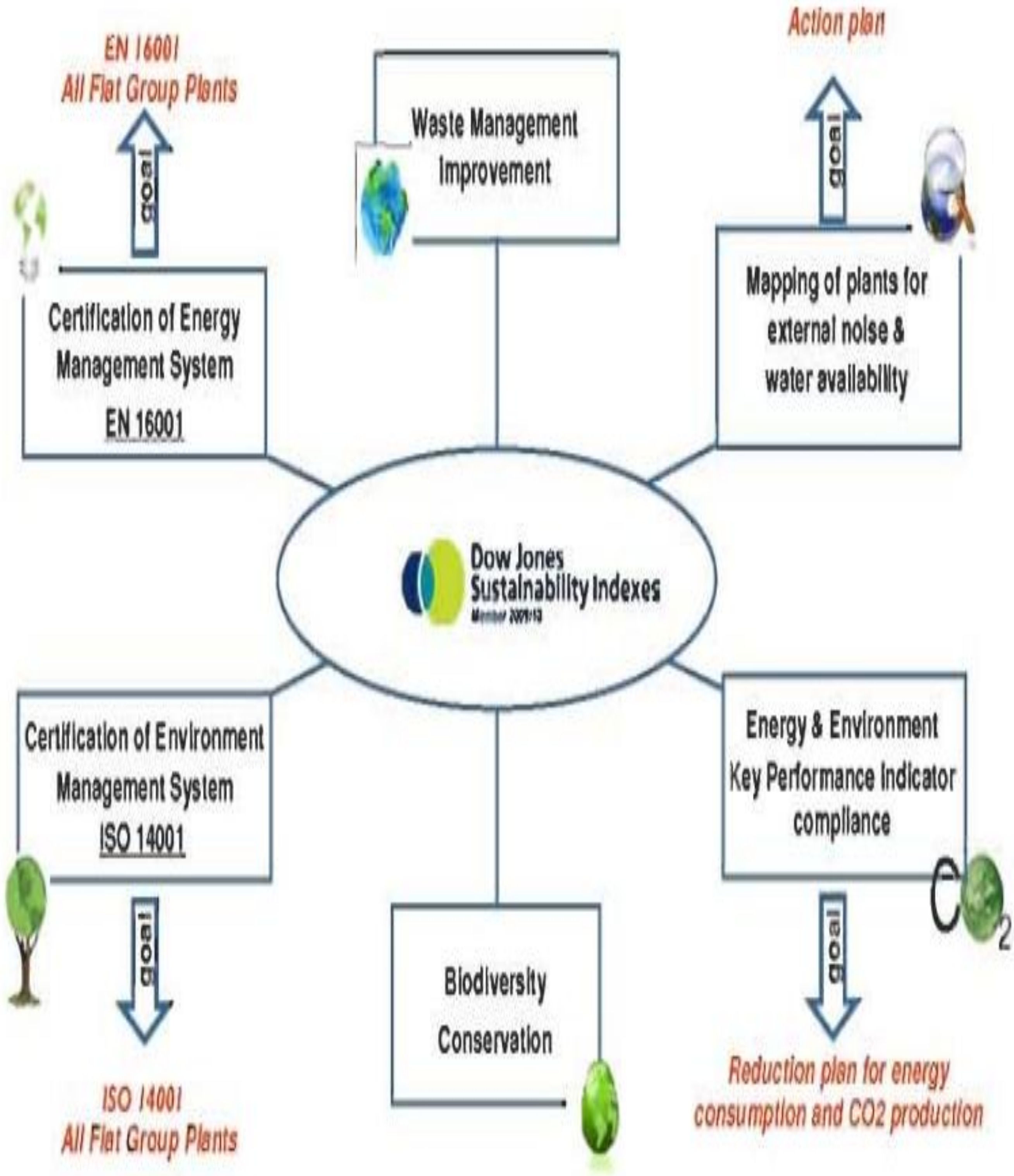


Figure 13: COMAU's Main Targets for Sustainability

5.2.1.5. Eco-innovation as Driver of Sustainable Manufacturing

As the last figure about COMAU displays below, Eco-innovation is the driver of sustainable manufacturing in the company.

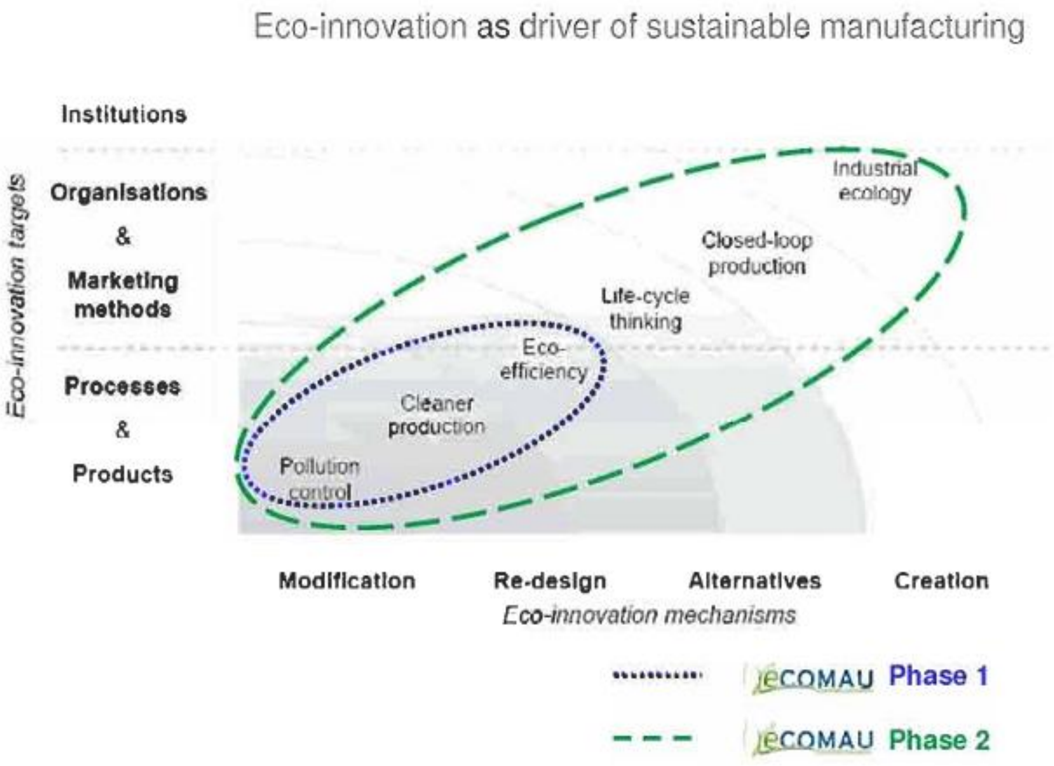


Figure 14: Eco-innovation as driver of sustainable manufacturing

5.2.2. BRIDGESTONE CASE

5.2.2.1. Information about Bridgestone

Bridgestone is established in 1931 and headquartered in Tokyo, Bridgestone Corporation is the parent company of the group.

Bridgestone has also built a large presence throughout the world, with tyres accounting for 80 percent of group sales. In diversified operations, the group's business spans industrial rubber and chemical products, office equipment components, sporting goods, and bicycles. The Bridgestone Group markets its tyres and other products in more than 150 nations and operates 58 tyre plants, 107 plants for diversified products and raw materials, and 5 technical centres in 26 nations around the world.

5.2.2.2. The Environmental Comittment

Bridgestone manages environmental, health and safety issues as integral and important parts of all its business activities. All tyres manufactured by Bridgestone Europe NV/SA are from plants certified according to the ISO14001 standard, where environmental improvement programs are defined annually.

Bridgestone Europe is one of the leading companies implementing an ISO14001 certified "Product Oriented Environmental Management System (POEMS)" in its European Tyre Design Centre. POEMS was introduced in 2002 to identify tyre design environmental features and apply continuous improvement activity in product environmental performance.

5.2.2.3. "POEMS" (Product Oriented Environmental Management System

The environmental impact of tyres (from raw material processing to final disposal of the product) depends mostly on product design and use.

The Bridgestone Product Oriented Environmental Management System (POEMS) organizes the efforts of different functions, competencies and resources towards a common goal: to continuously improve the environmental performances of our tyres. This tool has the required effectiveness, flexibility and simplicity to be applied in the dynamic and challenging working environment associated with the design activity of a key safety product such as the tyre.

5.2.2.3.1. What Does POEM Do?

POEMS starts with the identification and assessment of the environmental impact of a tyre. This "picture" of the situation is called LCA (Life Cycle Assessment) and was created in 2001. The tyre LCA shows that the use of the tyre is a key phase affecting the environment and POEMS has since been implemented to improve the design of tyre environmental parameters affecting tyre use (noise, rolling resistance, wear).

5.2.2.3.2. How does POEM Work?

Some examples of POEMS applications are:

- Continuous monitoring and identification of environmental requirements and expectations from customers.
- Identification of responsibilities and operational activities for verifying and maintaining the product in line with all applicable laws and even anticipating future environmental requirements.
- Setting up practical programmes for environmental improvement outlining the responsibilities, time frame and necessary resources, while continuously setting challenging goals.
- Applying procedures to environmental material and compound design, in addition to the continuous control of environmental aspects of tyre ingredients in co-operation with suppliers.
- Effective training on environmental aspects for all personnel working in tyre design.

By applying the POEMS approach, Bridgestone Europe ensures that tyre environmental impact is reliably controlled from the beginning of the product concept through to completion of the entire design process, including key factors such as material selection and tyre geometry.

5.2.2.4. The Environmental Balance of a Tyre

The Life Cycle Assessment (LCA) study conducted by the European Tyre and Rubber Manufacturers' Association in 2001 applies to a representative European passenger car tyre, based on data from various countries and tyre brands in Europe. It does not therefore apply to truck tyres or specific Bridgestone car tyres although, as a member of the Technical Working Group, Bridgestone played an active role in the study.

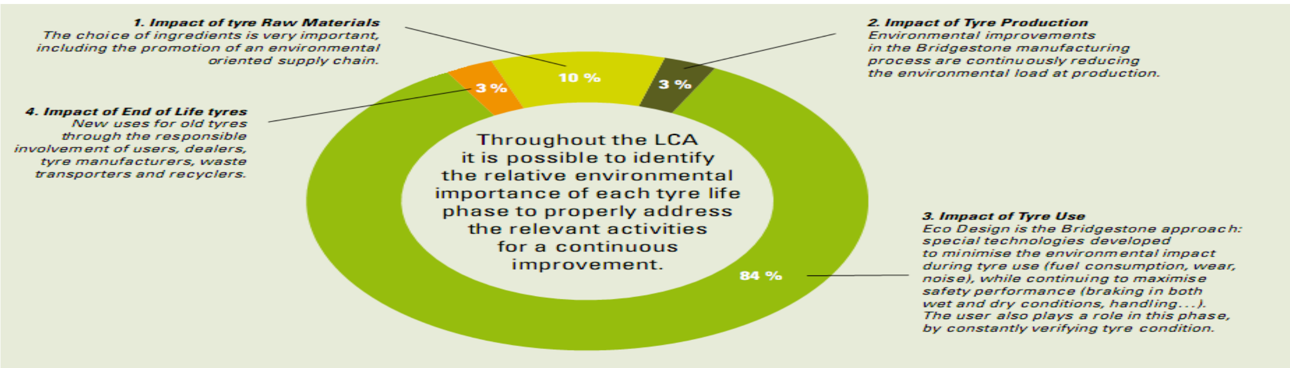


Figure 15: Environmental Balance of a Tyre

The use phase makes the largest contribution to the environmental load in the life of a car tyre. The end of life-phase makes a relatively low contribution to the overall load of the life cycle and has a lower impact than the raw material and tyres production phases as a whole.
The contribution of new tyre distribution transport and end-of-life collection transport has little significance compared to the other stages of the life cycle.

5.2.2.5. The Choice of Ingredients

Considering the results of the LCA study, Bridgestone reviewed its raw material in order to decrease the environmental effects, industrial waste and improve the working conditions of the workers.
Although every type of tyre is using more or less the same type of raw material, the portion of each raw material is depended on the type of the tyre. A passenger car tyre consists of synthetic and natural rubber, to which a range of specific substances is added, to ensure performance, durability and safety. The name of main ingredients, why they are used and their portions among other raw materials are illustrated below.

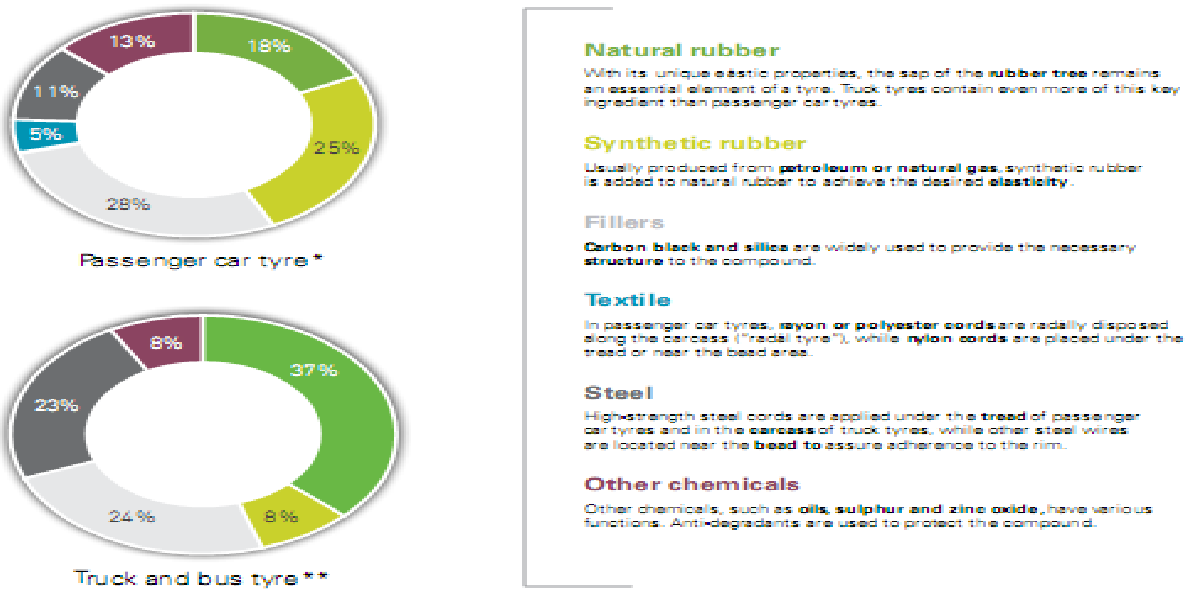


Figure 16: The Choice of Ingredients

Reduce, re-use, recycle - Bridgestone has adopted a range of waste reduction initiatives as part of a wider effort to limit its ecological footprint. Most of the zinc oxide used in tyres is made from recycled zinc, for example. Other relevant recycled materials include crumb rubber, a substance generated by crushing the waste rubber of used tyres. However, a high proportion of recycled rubber tends to translate into a loss of chemical reaction in the compound, increasing tyre wear and rolling resistance and consequently reducing service life and fuel efficiency. The limited and unstable supply of high-quality crumb rubber adds another layer of complexity. Bridgestone uses post-consumer recycled tyre material in all its tyre lines, but limits the crumb rubber content to small amounts that cannot affect the quality of the product.

5.2.2.6. Selection of Suppliers

Within the framework of POEMS, environmental criteria are a factor in the selection of suppliers and their compliance with legal and other requirements through the chain is strictly verified by Bridgestone Europe. A supplier with ISO14001 certification receives a selection advantage through a ranking system.

5.2.2.7. ECO-DESIGN: The Results of the POEM Process

Environmental effects in use phase

The LCA study for passenger car tyres assessed the following key tyre environmental aspects related to the use phase:

- Rolling resistance
- Wear performance
- Noise

During the use phase Bridgestone Tyres help to reduce the consumption of fuel by its design characteristic. Recent studies by Bridgestone on truck tyre performance reveal how longer tyre wear-life reduces fuel consumption. For example, fuel accounts for approximately 21% of commercial fleet operating costs in Europe, with tyres representing around 2%.

Major factors which can reduce fuel consumption include:

- vehicle and tyre maintenance standards
- vehicle aerodynamics
- driving style
- operational variables (speed, route, load, …)
- uncontrollable variables (weather, road surface, …)
- tyre rolling resistance

Each factor needs different strategies to be decreased or eliminated. Mainly the majority of these could be eliminated or decreased by some change in design characteristics or increasing consumer awareness about product characteristics and their usage behaviours to the environment.

In order to decrease the environmental effects in the use phase which could be translated into "change in fuel consumption" Bridgestone identified the key factor to be addressed.

Rolling resistance is the force required just to roll a tyre. It exists because a tyre deforms when rotating, resulting in energy losses in the form of heat. Air resistance and friction between tyre and road add further to the rolling resistance. The higher the tyre rolling resistance, the more fuel is required to move the vehicle forward.

Energy saving is also one of the important environmental aspect for Bridgestone. Great efforts have been made to raise fuel economy by focusing on lowering tyre rolling resistance while ensuring good traction and handling at the same time. Bridgestone has developed and continues to develop new approaches to tyre design and innovative materials to reduce rolling resistance without compromising safety. SILICA Technology improves grip and road holding, especially in wet or low temperature conditions. Silica also significantly reduces energy loss from the tread compound, thus reducing rolling resistance. Silica is an innovative reinforcing material in the tread compound, used wholly or partially as a substitute for carbon black.

Considering these factors Bridgestone is developing its tyres For example, with Bridgestone truck tyres

- rolling resistance significantly decreases over the full tyre service life
- high performance of tyre service life: commercial fleets need fewer new tyres, reducing the disposal of end-of-life tyres.

Bridgestone truck tyres are designed to provide a longer service life. Long-term testing shows that Bridgestone tyres last around 10% longer than comparable tyres from Bridgestone's competitors. This leads to lower average rolling resistance over the life of the tyre, with consequent benefits in terms of fuel consumption and vehicle emissions.

Friction of the tyre on the road surface ensures adherence (or "grip") but results in wear which generates particles from the tread ("tyre debris"). The wear rate depends on both the design of the tyre and the driving style, as well as the micro-roughness of the road, the maintenance level of the vehicle and the tyre inflation pressure.

Incorrect tyre inflation pressure, especially under-inflation in comparison to the manufacturer's recommendations, accelerates the phenomenon of wear, and increases fuel consumption.

Bridgestone Europe has developed HA-oil free compounds and is in the process of converting to aromatic-oil-free production within the time frame set by the Directive.

The improvement of wear performance, while maintaining a balance in overall tyre performance, remains an environmental target. Some Bridgestone products feature "FLAT FORCE BLOCK" Technology, where an improved tread-block design provides more uniform contact pressure, resulting in a smoother ride. Moreover "JOINTLESS" Technology improves high-speed handling, durability and uniformity. It consists of a spiral winding of nylon overlays which constrains the belt package under the tyre tread.

Based on research conducted by Bridgestone Europe in 2006, 55.6 milion tyre/year are lost due to under-inflation representing 5 bilion euros/year. The higher the wear rate, the higher the generation of both tyre debris and end-of-life tyres.

Bridgestone is not only working on its products design characteristic but also working on changing consumer behaviours by different means. Through a joing initiative with the FIA foundation in the "Think Before You Drive" campaign, Bridgestone Euroope performed checks on almost 30.000 vehichles in 19 European countries in 2005 and 2006 and distributed tyre pressure and tread depth gauges. In addition, Bridgestone Europe distributed leaflets to encourafe drivers to be more aware of basic safety measures, including the need to monitor their tyres and maintain them in good condition.

5.2.2.8. ECO-DESIGN : End of Life

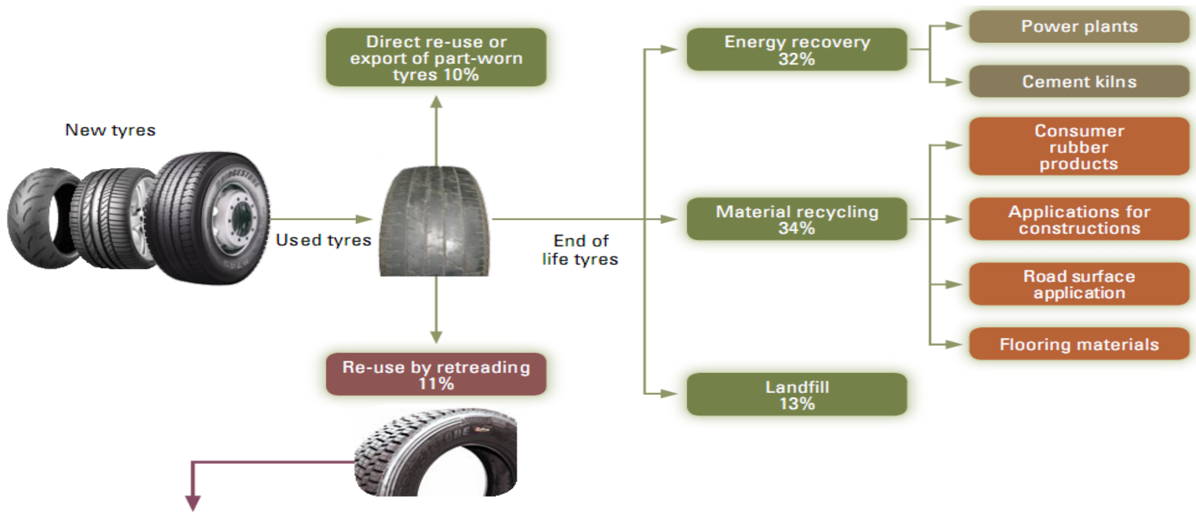


Figure 17: End of Life for Tyres

A retreaded tyre is a tyre which has been given a second life. This is achieved by applying a new tread to the worn tyre.

What are the features and advantages of a retreaded tyre?

- Safety: retreaded tyres are manufactured to very high standards, using highly sophisticated machinery and processes to ensure safety and performance.
- Economy: by re-using the worn out tyre, production costs are significantly reduced. Retreaded tyres are sold 25% to 50% below the price of a comparable new tyre.
- Environment: benefits from the extended life span of the tyre. Around 2/3 of a truck tyre are re-used before the material needs to be recycled or disposed of.

Bridgestone Europe aims to provide transport fleets with retreaded truck tyres that closely replicate the features of new Bridgestone tyres.

To meet this goal, the Qualitread product line – a wide range of sophisticated retreaded tyres – uses the best of Bridgestone compound. Retreading also represents a step towards greater sustainability. The process requires no more than a third of the oil and of the energy needed to manufacture a new tyre. It also extends the service life of the tyre, reducing the need for recycling or final disposal.

5.2.3. PIRELLI CASE

5.2.3.1. Information about Pirelli

Pirelli Tyre is the operational holding company for a group involved in the design, development, manufacturing and marketing of tyres destined for various types of vehicles: cars, light vehicles and motorcycles (Consumer sector, 70% of revenue), buses, trucks, agricultural and earth moving machinery, and the production and marketing of steelcord (Industrial segment, 30% of revenue).

Within this market, Pirelli Tyre focuses in particular on the high-end segments characterised by elevated technological contents and high performance. These are segments in which Pirelli has established itself in positions of leadership with regard to both its car and motorcycle tyres: Pirelli tyres are today seen as synonymous with quality, emotion and ultimate performance.

Drawing on its technological expertise, the group has consolidated working relationships with the world's leading car and motorcycle manufacturers; partnerships that have translated into a number of homologations for models from all the leading automotive firms.

5.2.3.2. Organizational Structure

Governance of Sustainability is centred around the Sustainability Steering Committee. This high-level body was formed by the Chairman at the beginning of 2004 to guide the advancement of sustainability throughout the Group. The organisational structure is made up of a Group Sustainability Director, who reports directly to the Group General Counsel, a Group Sustainability Manager and company Sustainability Referents (responsible for each Group affiliate).

In September 2009 the Equal Opportunities Steering Committee was merged with the Sustainability Steering Committee, following a decision taken by the latter, to realise operating opportunities and efficiency in regard to matters that had effectively been part of Group sustainability management.

Pirelli devotes significant resources to management systems. The Group utilises these tools to improve the quality, effectiveness and efficiency of its processes, in view of continuously reducing impact on the health of its employees, on safety conditions in the workplace and on the environment.

The following management systems have been adopted:

- OHSAS 18001 for occupational health and safety
- ISO 14001 for the environment
- ISO 9001, ISO/TS 16949, ISO/IEC 17025 for product quality

The international SA8000 standard was adopted in 2004 as the benchmark for assessing the consistency of the Group’s conduct with the Social Responsibility principles set out in the standard.

5.2.3.3. ECODESIGN in Pirelli

In 2001 the study Life Cycle Assessment of an Average European Car Tyre (Prè Consultants B.V. on behalf of BLIC, 2001) highlighted the substantial environmental impact of a common tyre during its useful life, which is far greater than its impact during the other two phases, production and end of life. According to this prestigious publication, about 90% of this impact is attributable to fuel consumption due to friction between the tyre and the road surface, while the remaining part reflects the impact of the results of this friction (i.e. tyre debris). It has been estimated that during its life cycle, a tyre produces debris accounting for between 10% and 14% of the tyre's weight.
The impact of these debris particles is still being studied at the international level. The Pirelli Group is monitoring this issue through a continual exchange of information and experience with other tyre manufacturers, by participating on the specific working group set up by the World Business Council for Sustainable Development.
In order to minimise the environmental impact associated with tyre use, Pirelli is constantly engaged in the design and development of compounds and product lines that, by using new materials, innovative internal structures and different tread designs, can reduce rolling resistance while guaranteeing the same durability and performance of the tyre. Pirelli is actively developing and using a series of new, increasingly ecological materials for compounds.
In 2009 Pirelli conducted research on raw materials from renewable sources that will lead it to produce ecological silica derived from food processing scraps (rice husks) by 2010.

5.2.3.4. Raw material Selection

Raw materials are selected in order to reduce as much as possible the use of substances that are harmful to humans and the environment. Accordingly, Pirelli systematically evaluates the environmental and toxicological characteristics of any new chemical before using it in production processes.

5.2.3.5. Factors considered during design phase

The principal objective of research and development in the Truck Business Unit is to strike the right balance between all the characteristics that a tyre must have in terms of performance, total safety and environmental friendliness.

This means developing a tyre that is not limited to compliance with regulatory requirements governing integrity, eco-compatibility, and so on, but extends to all those elements or factors that a tyre must have to offer complete safety both for the driver and the world surrounding him.

In a truck tyre, eco-compatibility also means reducing weight, since this in turn reduces both the energy and the quantity of raw materials used to fabricate it. The use of recyclable raw materials plays a key role in design.

Another key aspect is tyre durability: not only its frst life, but also the number of retreads that can be realised on the same carcass translate not only into energy savings but also savings of raw materials. This involves reducing its overall environmental impact while remaining focused on improving the product's performance.

Pirelli maximises the retreadability of the carcass by starting with the quality of the design and materials of the new tyre. Consequently, the design is a key step. During development of the tyre, engineers take into account the variables that will play a role throughout its entire life cycle and have a major impact during reconstruction.

The R:01 Series has many ecological features. Over the entire life cycle of the tyre, considering not only the reduction in consumption and thus harmful emissions, the high level of retreadability and durability compared with the old model, raw material use has been reduced by 20% and energy consumption during the manufacturing process by 22%.

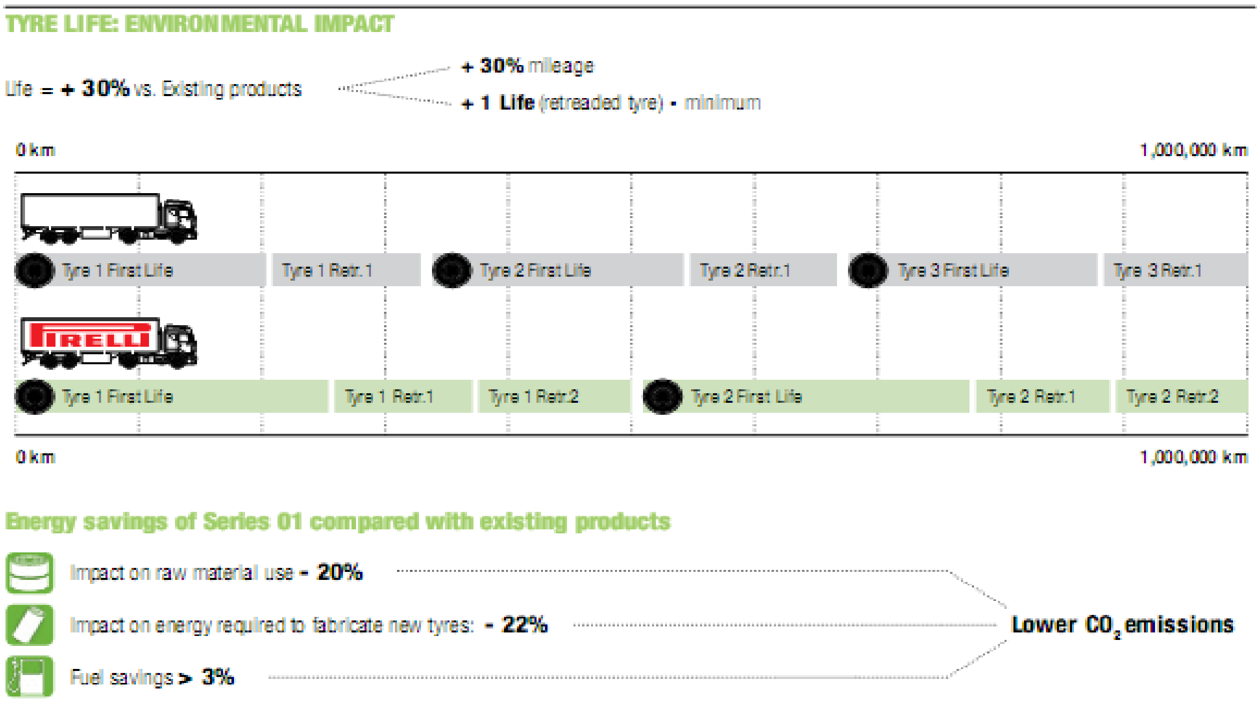


Figure 18: Tyre Life: Environmental Impact

5.2.3.6. ECO-DESIGN: Product Innovation

Normal use of a car whose tyre pressure is 20% less than its nominal pressure can cause fuel consumption to increase by up to 3% (with a consequent increase in air pollution). Studies by the U.S. National Transportation Safety Board have shown that for every 0.2 bars of under inflation, there is an average increase in fuel consumption of 1%. Furthermore, tyre pressure that is 20% below what it should be causes irregular wear on the tyre tread and consequently increases wear and tear by 25%, which translates into a 30% reduction in the lifetime of the tyre.

This is precisely why a tyre pressure monitoring system needs to be installed on the car. The simplest, surest and most economical way to increase the life of one's tyres, reduce gasoline, diesel or gas consumption and reduce the pollution caused by particulates released in the atmosphere is to inflate the tyres on one's car to their proper pressure.In order to act on this issue Pirelli created a system for measuring tyre pressure and temperature on original equipment: the Cyber™ Tyre "Lean". Consisting of a sensor that is little bigger than a 2 Euro coin mounted on the tyre inside the rim, it is the frst step towards a radical transformation of the tyre into an active system capable of transmitting data and information necessary for maintaining optimal pressure under all vehicle load conditions, with benefts both in terms of fuel consumption and driver safety.

5.2.3.7. End-of-Life Management of Tyres

A tyre's end-of-life phase makes a small contribution to the overall environmental impact of the entire life cycle of the tyre and has a decidedly less impact than those stemming from the use and production phases. Among the various final disposal options, burial in a landfill is by far the least desirable in terms of environmental compatibility. European Union Directive 1999/31/EC has prohibited disposal in landfills of entire end-of-life tyres (ELTs) since 2003, and of fragmented ELTs since July 2006.

About 3.3 million tonnes of ELTs were produced in Europe in 2008; 95% of these were recovered or recycle. The Pirelli Group has been dedicated for years to research on the management of ELTs, considering the major environmental benefits resulting from their recovery and recycling.

Through cooperation with Pirelli Labs, a number of possibilities have been developed for ELTs in terms of recovery of the raw materials that comprise them ("material recycling"), and recovery in the form of high-energy fuel ("energy recovery"), as a valid alternative to the use of fossil fuels.

This can include:

- the use of ELT granules in the production of sound insulation products;
- the production of powder to be used in the tyre production process;
- the use of ELTs to produce Pirelli CDR-Q, a fuel derived from high quality waste.

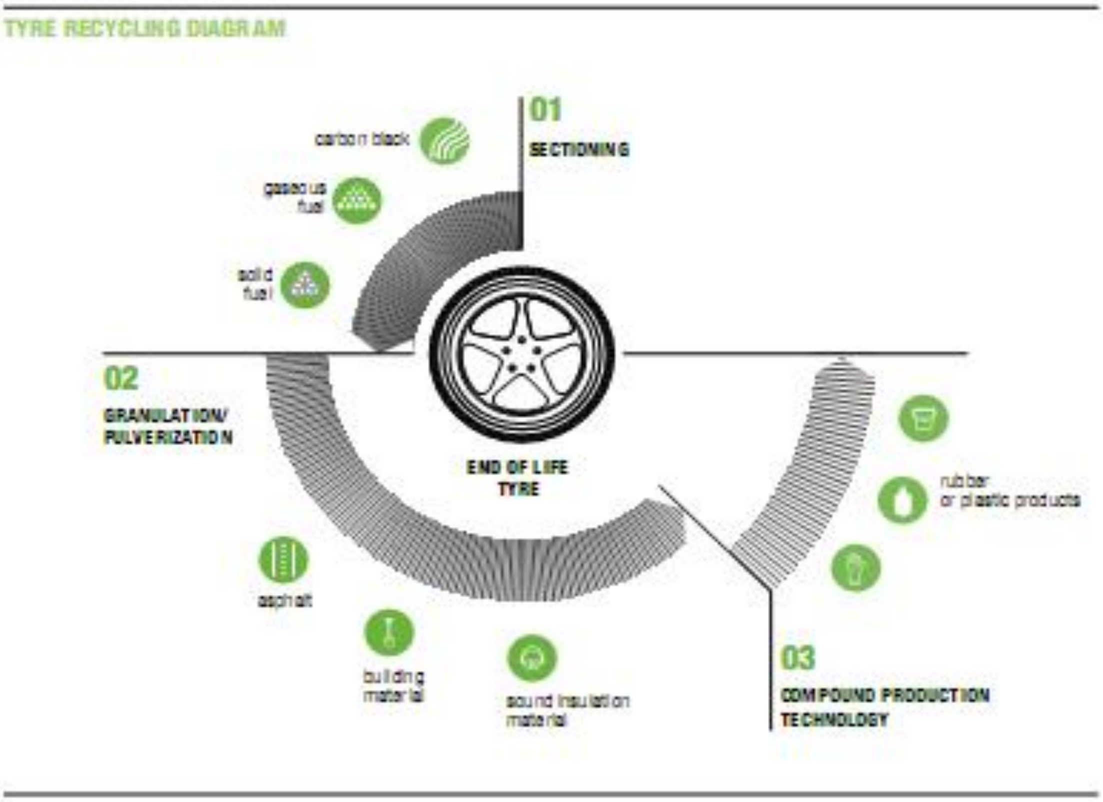


Figure 19: The Recycling Diagram for a Tyre

5.2.3.8. Eco-sustainability of Pirelli Processes

The Group operates a total of 25 production sites. These are distributed as follows:

- Pirelli Tyre: 4 in Italy, 5 in Brazil, 2 in Great Britain, 2 in Germany, 1 in China, 2 in Turkey, 2 in Romania, 1 in Argentina, 1 in Egypt, 1 in Spain, 1 in United States and 1 inVenezuela.
- Pirelli Eco Technology: 1 in Italy and 1 in Romania.

All Pirelli Tyre facilities have an ISO 14001 certified environmental management system that is co-ordinate at the corporate level by means of Group procedures. These procedures are also being modified and extended to the Eco Technology production sites.

6. CONCLUSIONS AND DISCUSSION

The concept of sustainable development has been gaining attention in recent years and the topic has risen to the top of the international political agenda, particularly owing to concerns over climate change. Growing media coverage of environmental issues and rising public awareness have further increased the pressure for manufacturing industries to take responsibility by adopting more advanced and integrated responses to environmental concerns.

The new world of sustainable technologies and work practices is undoubtedly a challenging and exciting emerging reality for the manufacturing industries. Key drivers of compliance, community expectations, risks, costs and market competition will ensure that those who don't adapt will be left behind. The role that manufacturing will play in creating and shaping this world is significant and will require steadfast commitment and effective strategies that embrace the full extent of sustainable possibilities. A sustainable organization will take a broad perspective of sustainability that includes environmental, social and economic criteria and engages the entire stakeholder community.

The traditional approach to environmental management in the manufacturing industry has evolved from pollution control as preventive strategies. Driven by new legislations, increasing costs of raw materials and consumer demand, producers are expected to be more conscious of the ecological consequences of their industrial activities, and need to take preventive actions to minimize the environmental impacts. This increased attention to the environment is presenting manufacturers with new challenges ahead. In light of increasing pressures to adopt a more sustainable approach to product design and manufacture, the requirement to develop sustainable products is one of the key challenges facing industry in the 21st century.

Recently, countries and society pay more and more attention to improve environment and one of the objectives to gain importance for the companies is to create environmental friendly products. One of the most striking areas where companies now have to be concerned is the environment. The concern regarding the impact stems from the fact that, whether we want it or not, all our products affect in some way our environment during their life span. As for this, there is today more and more focus on the environmental impacts of products during their whole life cycle. In particular, ecodesign aims at integrating environmental aspects during the product's design process as any other criterion, in order to reduce the life cycle impacts. Due to legislative pressure, customer requirements or even manufacturer's environmental policy, ecodesign is currently gaining popularity in all industrial sectors. Although a lot of product environmental impact assessment and Design for Environment tools already exist, environmental aspects are unfortunately rarely routinely integrated into product development process in the industry. This is mainly due to the fact that current ecodesign tools are little adapted to designers' practices, requirements and competencies.

As observed during the thesis work, ecodesign has not been routinely practiced in design teams. The use of ecodesign tools is still not prevalent in the industry and the implementation of ecodesign tools is not common. This is probably due to the facts that current ecodesign tools are too much expert tools that are little adapted to designers' current needs, tools and practices. If environment and more particularly recycling is to be more considered as any other parameter in the design process, tools will have to be adapted. Therefore, it is necessary that existing environmental impact assessment and ecodesign tools are revisited, and if possible connected to engineers' design tools currently used in companies.

Moreover, the most applied ecodesign tools are not considered as fully effective in their company practices. It can be seen as a result of one of the survey questions that LCA is considered one of the most effective ecodesign tools, even though its application within the surveyed companies is not so frequent. This could be due to the fact that an LCA study is prohibitive economically for most of the organizations interested in applying it. This is because of the fact that a holistic LCA is a very data-intensive and time-consuming procedure. The more comprehensive an LCA is, the more time-consuming and expensive it will be. High costs are partly caused by the need for professional consultation and expert knowledge in the stages of impact and improvement analyses.

In general, ecodesign is indeed little routinely integrated into the product development. This is however slowly changing and environmental experts are today more and more routinely involved in the design team. Ecodesign was traditionally mainly developed in sectors targeted by stricter environmental regulations, i.e. packaging, automotive and electronic industry. While ecodesign was in the past mainly driven by large groups and multinationals, it can be noticed today that small and medium-size enterprises are defining their own ecodesign strategies. However, despite the increasing importance of ecodesign in view of market requirements and regulations, a large number of enterprises still lack any experience with ecodesign.

In summary, we see that the application of ecodesign tools and methods by SMEs are limited as mentioned in literature. It is not just because of the respondents' answers to survey but also many companies that should/might apply sustainability approach and ecodesign tools returned to our mails regarding the survey as either they are not interested in the concept or they really do not consider such approaches during their product design.

Despite the progressive use of ecodesign in the industrial world, taking into account environmental constraints remains problematical for small and medium sized enterprises (SMEs), which seem to be remaining on the fringe of the movement. Beyond the lack of environmental culture in the enterprises, the problem stems from the ecodesign tools which have not been designed with any thought of integrating them into the enterprises' organization.

The fact that companies, mainly SMEs, do not feel the need to improve the environmental performances of their production, leaving this task to the final producer, can be seen as another reason why ecodesign methods are not so widely used. It is deemed, in fact, that a product has to be considered as a complex system, and its environmental performances are not determined only by its final design, but also by the performances of each one of its components and parts, as well as by their interaction.

Actually, it is unlikely that a company will make a choice that is not primarily economically driven. Furthermore, it is of crucial importance that new products meet market requirements. Therefore, there is a risk that the environment will not be the highest priority in some trade-off situations. The reason why companies mostly talk about or direct to environmental commitment is mostly a matter of marketing and advertisement. They try to enhance the image of the company and their products as well as looking forward to enter into new markets all of which could be considered as their long term objectives. For companies, the priority is obviously economic aspects. Then, environmental and social aspects follow respectively.

Although it has been mentioned in the literature that there is a growing interest toward sustainability, regarding the results of the survey it could be said that it is not the primary concern for their R&D studies. The level of investments of companies on sustainable products is mostly at low levels or even not available. The companies do not invest enough in sustainable practices. Their investments are mostly around 5-10 % of their R&D costs which would be considered as very low. Sustainability is not well integrated into product design yet. Companies’ investments regarding this area are low compared to their R&D costs. There is still a long road for the companies on this sustainable way and there is a significant gap between literature and companies’ practices.

According to the responses from the surveyed companies, most of the reverse environment effect is created during the Manufacturing phase, end of life and material acquisition activities. On the contrary, it has been stated within the Case studies of PIRELLI and BRIDGESTONE that the biggest reverse environmental impact is created during the use phase. Although this outcome is mainly dependent on the sector which the company is present in, it should be cleared out that these responses are due to the results of a scientific analysis like LCA. Analyzing the results of most applied ecodesign tools, it can be seen that most of the surveyed companies rarely apply LCA. Therefore, it might be right to say that this outcome, that manufacturing phase, end of life phase and material acquisition phase creates the biggest environmental impact could be driven from a general misbelieve within the industry.

Raw material & energy consumption and energy efficiency are the most important parameters considered by companies. Hazardous substances, recycling &disposal and waste minimization are other important factors. For the companies, energy related parameters have significant importance and play a major role in their decisions.

Proven also by our survey results, ecodesign improvement options only stand a chance, if they are supported by some stimuli related to Economical aspects apart from just environmental benefits. Moving deeper into the survey questions, it becomes more clear that most of the companies evaluate their designs mainly dependent on economically relevant aspects or regulatory relevant reasons such as hazardous substance usage, raw material and energy consumption, energy efficiency and recycling & disposition.

Quality and cost seem to be the most important factors considered during product design. As seen, environmental aspects and legal requirements are not the priority ones for the companies. They are still not forcing factors for companies.

When we look at the driving factors for the companies to implement ecodesign (factors that push companies in ecodesign practices), we see that “improving resource and process efficiency” and “cost saving” are significantly considerable driving factors for them. “Customer demand” follows these driving factors. Besides being easily understood by most of the users, it appears that legislation is perceived as a relatively strong driving force.

Companies mostly think ecodesign as achieving long term objectives. In reality, most of the decisions and interest depend on either costs or long term plans as image improvement and entering to new markets.

To speak regarding the benefits, “enhancement of the image of the company” is expected by all the companies involved in the survey. “Enhancement of the image of the product”, “Stimulation of innovation” and “New business opportunities” are other mostly expected benefits for the companies when applying ecodesign.

Companies do not use most of the types of ecodesign tools. Mostly used ecodesign tool seems to be LCA. Besides LCA, QFD based and checklist based tools together with design for recycling applications are other prevalent tools used in companies' practices. Most of the other tools present in the literature are not used and even sometimes not recognized by companies. There is a huge gap here between literature and the applications of companies.

The most important criteria for the companies in choosing ecodesign tools are that they want tools that are "easy to implement" and "easy to learn". "Delivering accurate results", "the amount of required information" and "availability of resources for the assessment" are the other important criteria referred by companies.

Companies use mostly ecodesign tools in product planning and embodiment design and the 2 dominant ecodesign types are "product improvement" and "product redesign" for ecodesign practices as expected.

However, as product development processes and organizations differ from company to company, depending on their specific needs and requirements, the integration of eco-design also differs.

The choice of the right tool and/or method, for the right purpose, by the right person and at the right moment, is a critical issue, which should be fully 'incorporated' in a company's eco-design practices. It is essential to articulate design and design processes and to test them in real life to assess their robustness.

As eco-design practices are currently being developed and implemented in companies, no real conclusions can be made at the present time. Apparently, motivation and creativity of all actors will be needed in the near future to really take up the challenge of sustainable design.

The integration of environmental considerations into the product development process is vital for the success of eco-design and even for product development in general. Eco-design should not be viewed as an additional requirement, but rather as a broadening element which can enhance production, use and the end-of-life stages of products.

Companies need to develop a better understanding of the implications of sustainability for their business and that the companies already doing so are seeing significant benefits. In the near future, ISO 14000 may cause an even deeper ripple effect, augmented by increased awareness through education.

New ecodesign tools and methods should be developed to be usable in early design stages, so that real innovation and environmental benefits can be achieved. Ecodesign will only be robust and fully efficient when these challenges will be taken up.

To sum up, the thinking and practices surrounding sustainable manufacturing have evolved in several ways in the last decades, from the application of technology for the treatment of pollution at the end of the pipe through prevention of pollution to minimizing inputs and outputs and substituting toxic materials. Recently, manufacturing companies have focused on solutions that integrate methods of minimizing material and energy flows by changing products/services and production methods and revitalizing disposed output as new resources for production. Advances towards sustainable manufacturing have also been achieved through better management practices. Environmental strategies and management systems have allowed companies to better identify and monitor their environmental impacts and have facilitated improvements in environmental performance. Although such measures were initially limited to plant-specific production systems, they have evolved towards support for better environmental management throughout the life cycle of products and the value chain of companies.

7. RECOMMENDATIONS AND FUTURE RESEARCH

From this research, we realize that this topic is still at its the earliest stage and the extensions of this research filed are unlimited. Here we recommend the following topics by worthy of further study:

1. The survey would be analyzed again after higher number of responds from the industry and statistical methods could be applied after reaching adequate number of replies for statistical significance.
2. A modified or new method of integrating sustainability criterions into the product development processes that fill the existing gap would be developed for a better application in the industry.
3. Assessment of the practicality and feasibility of the new methodology into to a factual design process would be carried out after the previous step.
4. Sustainable product design in a SBCE (Set Based Concurrent Engineering) environment would be analyzed.
5. In the near future, ecodesign of products will also have to be adapted to new productive paradigms such as Product / Service / System and Remanufacturing. These paradigms are indeed developing, obviously not only for environmental reasons, and ecodesign should be robust to these developments. Innovative ecodesign tools and methods would be developed in order to be used in the earlier phases of the product's design, so that real innovation and environmental benefits can be achieved.

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9. APPENDIX

Ecodesign Product Survey_Politecnico Di Milano_Dep. of Management, Economics and Industrial Eng.

1. Ecodesign Product Survey

EXPECTED TIME TO ANSWER THE SURVEY : 30 MINUTES

Eco-design Product

Questionnaire

INTRODUCTION

Product development is one of the most critical aspects for companies in reaching their sustainability objectives. However, the support needed for making sustainability related decisions are not systematically integrated in most companies today. So, it is a necessity to create generic methods and tools that helps the integration of sustainability aspects in decision making and product development. In order to reach such an objective, it is necessary to know the available design tools, main differences in their approaches and the synergies in between.

Taking the above points into consideration, the main objective of this questionnaire is to understand how and what companies are doing currently to integrate sustainability into their products and product design processes. With the help of the survey, we intend to identify the gap between the literature and the practice. The results of the survey would be used to develop a modified or a new method of integrating sustainability criterions into the product development processes that fill the existing gap.

This survey is composed of questions about company characteristics, sustainable strategies and applications of the company, ecodesign tools and relevant product development processes in order to find an answer to above questions.

1. What is the name of the Company and which sector does the company serve?

2. Do you consider sustainability approach in your product development processes?

- Yes
- No

3. How would you define briefly your sustainable product strategy?

4. What is the level of investment on sustainable products compared to R&D costs?

- N/A
- <5%
- 5-10%
- 10-25%
- 25-40%
- More than 40%

5. Which environmental regulations/policies does the company concern?

- [ ] RoHS (Restriction of Hazardous Substances)
- [ ] WEEE (Waste Electrical and Electronic Equipment)
- [ ] REACH (Registration, Evaluation, Authorisation and Restriction of Chemical substances)
- [ ] ELV (End of life vehicles)
- [ ] IMDS (International Material Data System)
- [ ] EuP (eco-design requirements for energy-using products)
- [ ] Packaging regulation
- [ ] ISO 14001 Certified Environmental Management System
- [ ] EH&S Policy (Environment, Health and Safety Policy)
- [ ] Other (please specify)

6. Please estimate as a percentage the dependence of the company's sustainability related decisions on the following 3 pillars of sustainability? (Sum of all choices should be 100)

Economic aspects

Environmental aspects

Social aspects

7. Regarding your product range, how would you rate the severity of the adverse environmental impacts observed in the following life-cycle stages?

	Severe	Moderate	Slight	None
Material Acquisition				
Manufacturing				
Distribution				
Use				
End of life				

8. Which environmental parameters are used for evaluating environmental aspects in your product design?

- [ ] Hazardous Substances
- [ ] Raw Material and Energy Consumption
- [ ] Recycling and Disposal
- [ ] Packaging (recyclable material)
- [ ] Waste Minimization
- [ ] Material Recovery
- [ ] Energy Efficiency
- [ ] Source Reduction
- [ ] Material Content
- [ ] Water Consumption
- [ ] Toxic Dispersion
- [ ] Use of renewable resources
- [ ] Product Durability

9. How would you rate the company's consideration of following factors during product design?

	Not important	Somewhat important	Important	Very important
Cost				
Quality				
Function				
Ergonomics				
Safety				
Environmental aspects				
Legal requirements				

10. How would you rate the importance of the following driving factors for the company to implement ecodesign?

	Not important	Somewhat important	Important	Very important
Improving resource and process efficiency				
Potential Product differentiation				
Cost saving				
Reduction in regulatory burden and potential liability				
Customer demand				
Competitors' activities				

11. How would you rate the following internal stimuli (reasons why ecodesign option is interesting, regardless of the influence of external parties) regarding your company's sustainable prod design?

	Mostly	Sometimes	Rarely	Never
The company expects a reduction of the environmental impact (commitment to reduce the environmental impact)				
The company expects a reduction of costs (lower cost-price of the product)				
The company expects an image improvement (leading to competitive advantage)				
The company expects new market opportunities (competitive advantage: increasing actual market share/access to new markets)				
The company expects an increase of the product's functional quality				
The company expects a synergy with product requirements other than functional quality demands or low costs				
The company expects a synergy with product requirements other than functional quality demands or low costs				
The company expects a commercial benefit, other than those mentioned in previous (e.g. synergy with care systems, risk reduction, increased efficiency in production, storage, distribution, etc.)				
The company regards the option as an interesting long-term innovation opportunity				
The company perceives another internal stimulus				

12. What kind of barriers you face standing in the way of the suggested ecodesign improvement options and how often?

	Mostly	Sometimes	Rarely	Never
Doubt about the environmental benefit of the option suggested				
The company does not feel responsible for realizing the option				
The option only becomes relevant if supported by environmental legislation				
The option creates a commercial disadvantage for the company				
The option creates a conflict in connection with actual functional product requirements				
The option is not a challenging technological innovation opportunity for our company				
Realization depends on available technical possibilities; at the moment there is no proper alternative				
The company regards new investments in redesigning the product in question as fruitless				
The company lack sufficient time to realize the option in question				
The company perceives another type of barrier				

13. What kind of benefits do you expect to get by applying eco-design?

- Cost saving
- Stimulation of innovation
- New Business Opportunities
- Improved Product Quality
- Improved resource and process efficiency
- Increased market share
- Other (please specify)
- Enhancement of the image of the product
- Enhancement of the image of the company
- Stronger competitive advantage
- Preservation of crucial resources
- Increased productivity and quality
- Stronger sales and customer loyalty

14. Do you use any ecodesign tools in your product design processes?

- Yes
- No

15. For how long have you been adopting ecodesign tools?

16. Which ecodesign tools are used in company's practices? How would you rate the frequency of use and Effectiveness of concerning tools?

	Never	Sometimes	Always	Not Effective	Somewhat Effective	Very Effective
LCA-based (Full LCA, Streamlined LCA, etc...)						
QFD-based (EQFD, GQFD, etc...)						
Checklist-based						
Strategy-Wheel						
Environmental Effect Analysis (EEA)						
Matrix Based						
Design for Recycling						
Design for Safe Disposal						
Design for Disassembly						
Design for Remanufacturing						
Other						

If there are other tools used, please specify

17. How would you rate the importance of the following criteria when choosing the suitable ecodesign tool in your company?

	Not important	Somewhat important	Important	Very important
Easy to learn				
Easy to implement				
Deliver fast results				
Deliver accurate results				
The amount of required information				
Comprehensive (life cycle stages / impacts)				
Less data intensive				
Deliver simple results				
Availability of resources for the assessment				

18. Is there any mechanism to use the output of the previous ecodesign projects to improve the accuracy of the ecodesign tools?

- No
- Yes

If yes, please specify briefly how

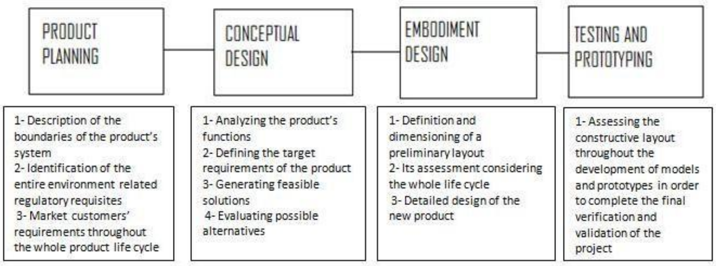
19. Do you make any simplifications during environmental assessment of the product? If yes, how would you rate the frequency of use of the following simplified approaches in the following table?

	Never	Rarely	Sometimes	Usually	Always
All processes prior to final materials manufacturing are excluded					
All processes after final materials manufacturing excluded					
Only primary materials manufacturing is included, as well as any pre-combustion processes for fuels used in manufacturing					
Selected entries are used to approximate results in all impact categories, based on mass and subjunctive decisions; Other entries within each category are excluded					
Using qualitative or less accurate data					
Selected processes are replaced with apparently similar processes based on physical, chemical, or functional similarity to the database being replaced					

20. If you ever faced a failure during your eco-design projects, what was the main cause for it?

	Mostly	Sometimes	Rarely	Never
Lack of knowledge about environmental issues on the part of people involved				
Existence of too many uncertainties				
Lack of understanding regarding the impact of ecodesign on areas such as regulation, cost reduction, competitive advantage and organizational image improvement				
Lack of consensus about how to evaluate products in environmental terms				
Lack of relevant standards				
The belief that environmental goals are necessarily at odds with economic objectives				

INTRODUCTION FOR THE NEXT QUESTION



21. How frequently are ecodesign tools used in above mentioned NPD process phases in the company?

	Never	Rarely	Sometimes	Usually	Always
Product planning					
Conceptual design					
Embodiment design					
Testing and prototyping					

22. How would you compare ecodesign implementation to overall product development process of the company in terms of cost and time spent?

	Very Low	Low	Moderate	High	Very High
COST					
TIME					

INTRODUCTION FOR THE NEXT QUESTION

There are four types of ecodesign stages in accordance with the degree of achieving eco-efficiency (see figure). 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.

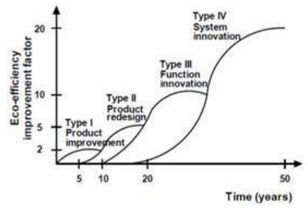


Figure: Four types of ecodesign (Rathenau Institute 1996)

23. Considering the four types of ecodesign stages in accordance with the degree of achieving eco-efficiency, which types are used in company's applications and how frequently?

	Never	Rarely	Sometimes	Usually	Always
Product improvement (Type I)	◯	◯	◯	◯	◯
Product redesign (Type II)	◯	◯	◯	◯	◯
New product concept definition (Type III)	◯	◯	◯	◯	◯
New product system definition (Type IV)	◯	◯	◯	◯	◯

OPTIONAL PART

24 AND 25 ARE OPEN QUESTIONS AND RESPONDING TO THESE QUESTIONS IS OPTIONAL

RESPONSES WOULD BE HIGHLY APPRECIATED

24. Have you observed any significant internal changes in company practices after ecodesign implementation?

◯ No

◯ Yes

If yes, please specify briefly

25. What kind of obstacles you face when integrating sustainability in NPD processes? (Please list all or explain briefly)