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ECO-DESIGN VALUE ALIGNMENT

– KEYS TO SUCCESS –

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In a world of globalization and outsourcing, environmental legislation became a main driver for doing eco-design. Eco-innovation and green money are concepts to create marketing advantages and differentiation from their competitors, transforming a legislative handicap into financial benefits and societal recognition. This research introduces Life cycle Environmental Value Chain Analysis (LC-EVCA) and Environmental Worth Analysis (EWA) to identify the stakeholders implementing environmental improvement programs and the value relationships among them. Life cycle information and societal concerns are the keys to success for the eco-design value alignment. Philips environmental programs and a brief example illustrate how eco-design can be integrated into product development, and how both customer (society) and producers find themselves in a win-win situation.

1. INTRODUCTION

Eco-design is the systematic consideration of the design performances with respect to environmental, health and safety objectives over the full product and process life cycle (Fiskel and Wapman 1994). It is actually possible to focus on a specific stage of the life cycle such that the environmental impact is minimized at that stage as well as emphasizing the entire life of the product.

Eco-design is known by numerous other names such as green design, design for environment, sustainable design, environmentally conscious design, life cycle design, life cycle engineering or clean design. It takes place early in the product's design or upgrade phase, to ensure that the environmental consequences of the product's life cycle are understood before manufacturing decisions are committed.

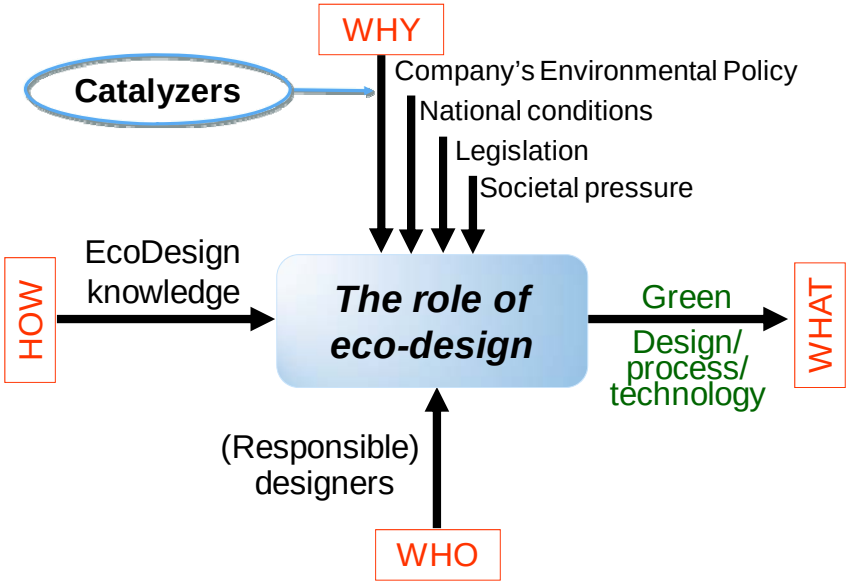

Figure 1 The role of eco-design

Obviously, when designing sustainable products, other constraints including economics, technological possibilities and limitations along with the benefits to the customer have to be considered (Luttropp 1999). The environmental demand, economic reality and technical possibilities must be optimized when designing for a sustainable society (Luttropp and Züst 1998).

Researchers have analyzed various stages of the product's life cycle and developed methodologies to improve the design of the product from an environmental perspective. Consequently, eco-design was broken down into many stages including product's manufacturing,

use and end-of-life (EOL). According to Horvath (Horvath et al. 1995), to achieve eco-design, three main goals must be pursued:

- minimize the use of non-renewable resources
- effectively manage renewable resources
- minimize toxic releases to the environment.

Goals may be translated into specific eco-design strategies. For example, in order to minimize the impact on environment at the manufacturing stage, design objectives may include design for energy conservation to reduce the energy used and minimization of the wastes during the production. In order to reduce the energy consumption during the use phase, strategies like Design for Energy Savings were developed. Beside the production and use phases, the EOL phase has received an increased attention during the last decade. Numerous methodologies were developed, having as driving factors the increased awareness of the society, and lately the new regulations. The most popular of the strategies are Design for Maintainability/Serviceability, Design for Reuse, Design for Remanufacturing, Design for Disassembly and Design for Recyclability (Recovery).

The following sections will analyze three challenges eco-design faces in the 21st century. In a world of *globalization and outsourcing*, *environmental legislation* becomes a main driver for doing eco-design. *Eco-innovation* and green money are concepts used by companies to create marketing advantages and differentiate from their competitors, transforming a legislative handicap into financial benefits and societal recognition.

2. GLOBALIZATION – THE NECESSARY EVIL

Globalization, as an opening and intensification of the relationship between nations with respect to the exchange of goods, services and capital (human capital included), “is leading to similarities in activities of individuals, practices of companies and policies of governments” (Czinkota and Ronkainen 2005). Although this has been happening since 1947 when the General Agreement on Tariffs and Trade (GATT) was signed, the outsourcing and relocation of western companies in new emerging economies like China and India (counting together for 30% of the global population) is amplifying the existing social (unemployment) and environmental concerns.

There is little rigorous study supporting the link between globalization and the current environmental problems. Nonetheless, the common opinion of the authors that tackled the subject converges to: "… Globalization process and trends add to environmental deterioration, to diminishing control of environmental problems by modern institutions and to unequal distribution of environmental consequences and risks between different groups and societies. The dominance of the economic globalization process is often believed to be the root cause of these detrimental environmental effects" (Mol 2001).

Some reasons supporting the belief that globalization worsen the environmental problems vs. reasons supporting the opposite belief are summarized in Table 1 (Speth 2003).

Table 1 Pros and cons

Cons	Pro
Expansion of the environmentally destructive growth	Global firms can spread the most advanced environmental management technology and techniques
Decrease in the ability of national governments to regulate and cope with environmental challenges	Strengthening of capacities in government to manage economic affairs may strengthen environmental management practices
Increase in corporate power and reach	Increased incomes which can lead to governmental revenues for environmental programs and increased public demand for environmental amenity
Stimulation of sectors like transportation and energy that have large environmental side effects	Increased international trade could lead to higher prices, more secure property rights
Increase of likelihood of economic crises	
Commoditization of resources	
Spatial separation of action and impact from responsibility	
The further ascendancy of the growth imperative	

A study performed on Japanese companies aiming at identifying factors influencing their environmental performance revealed a strong correlation between globalization (expressed as *foreign direct investment* and *exports*) and the environmental performance. Possible explanations include (Cole et al. 2006):

- global firms are likely to employ the strictest operational standards cross countries, thus raising the standards in the local country
- overseas affiliates are more likely to employ advanced technological solutions in order to maintain a competitive edge and to thus compensate for any lack of local knowledge
- a centralized environmental management systems of overseas affiliates in the source country gives the impression of strong domestic investment in environmental management systems
- global firms may be subject to closer national and international monitoring than domestically owned ones.

These conclusions are sustained by other studies whose findings are that trade openness promotes multilateral environment cooperation (Neumayer 2002) and globalization. Their wise and fair management represents a great promise for the sustainable development (Neumayer 2006).

Design is an activity that has strongest influence over the product life cycle, which at its turn will influence the image and the environmental performance of a company. This is why, analyzing the product life cycle is critical for finding out what is the role of eco-design in the globalized market.

As opposed to the closed economy concept, based on producing and consuming locally, with little or no interaction with the external market, the challenge with the global markets is threefold because the following typical situations may occur:

1. Manufacturing takes place outside the country for which products are sold and where the development takes place

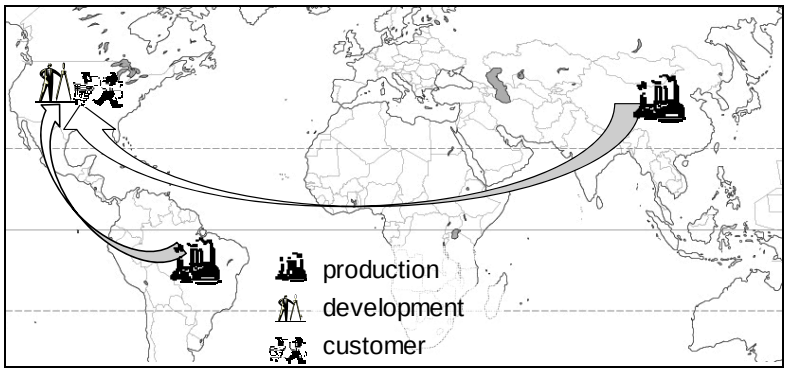

Figure 2 Outsourced manufacturing

2. Product is intended for multiple markets across the globe, which economically and culturally can be very different.

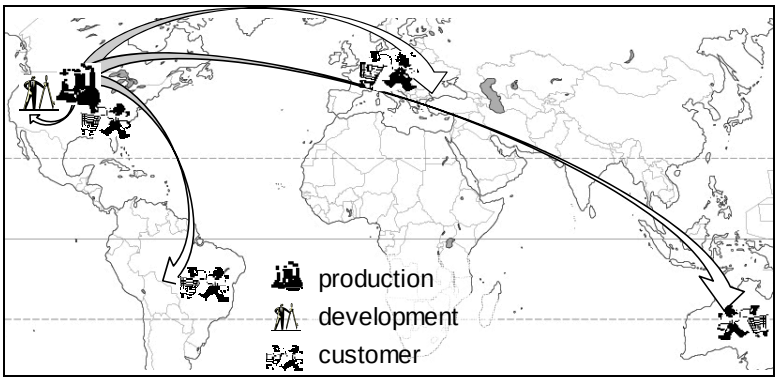

Figure 3 Global products

3. A combination of the two, where development and/or manufacturing are distributed across the globe and production is intended for multiple markets (global products globally engineered).

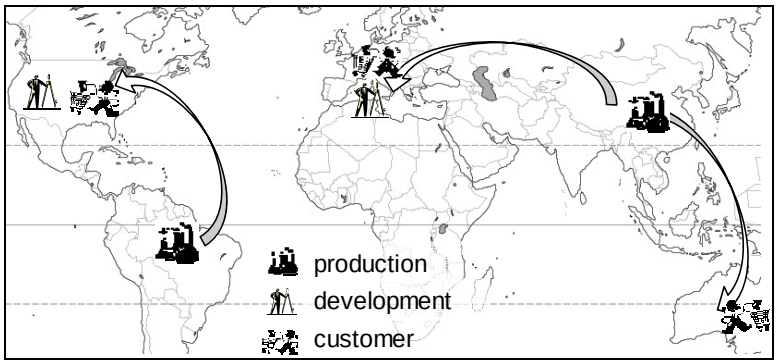

Figure 4 Global products globally engineered

The role of eco-design, in its traditional meaning is to help design so that the environmental impact is reduced during the whole life cycle. The following qualitative analysis positions the eco-design in the context of globalized markets.

Materials

Material use reduction is one of the main issues addressed by eco-design for the energy using products, and it is the priority for products not using energy. Whether they are manufactured close to the customer or not doesn't make any difference in terms of quantity of material needed. The difference comes from the environmental burden created by the extraction of raw materials. Globalization may shift the raw material extraction to the manufacturing region (China, Mexico,

India, etc.), which in most of the cases happens in countries with older and more energy intensive technologies, where the legislation is less restrictive in terms of emissions, waste, human health and safety. On the other hand, the life cycle perspective may include in the material selection analysis the location of the production site.

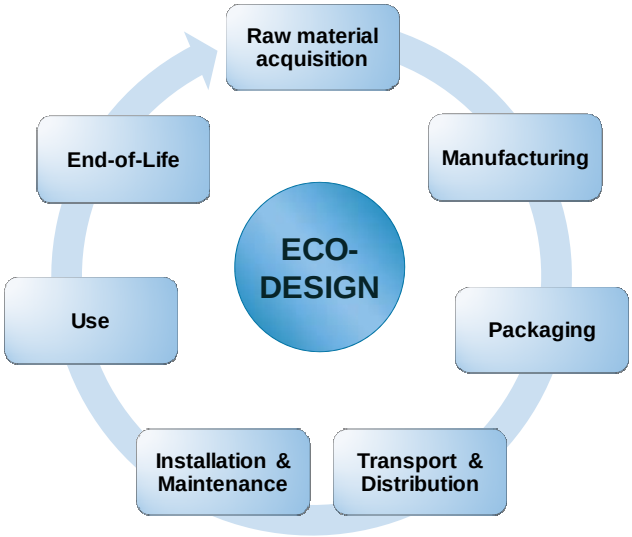

Figure 5 Eco-design as the center of product life cycle

Manufacturing

Eco-design influences the efficiency of the manufacturing process as well. From the point of view of eco-design, decisions on the choice of the manufacturing processes are trade-offs between economic and environmental criteria. Outsourcing allows less control over the manufacturing processes, and there may be a high discrepancy between the design intention (and thus the estimated environmental performance of the processes) and reality at the supplier (different manufacturing processes, waste management, etc.). In most of the cases this is detrimental to environment and the eco-design may become a simple game of chance.

Packaging

Packaging has several roles: protect, handle, informs on the product and promotes the brand. Shipping to and from overseas dramatically increases the number of manipulations, and thus the risk of failure due to shock exposure. From a design point of view it implies that either the product should be less sensitive to shocks or the package should be designed to better protect it. Also, a double packaging may take place (bulk packaging and later individual at the distribution centers). Either way, it acts against the eco-design principles to reduce the quantity of packaging.

Transport and distribution

The huge increase in the distance a product travels before reaching the customer, as opposed to locally produced goods, is probably the main negative effect on environment. Although these are the consequences of prevailing economic decisions, optimizing the weight and/or the volume of the product and its package plays an important role in reducing both environmental impact and cost due to transportation.

Use

From an environmental point of view the use phase contributes the most to the environmental impact for two broad categories: energy using products and products making use of consumable. Eco-design aims at reducing the energy consumption (useful and standby where applicable) and the quantity of consumables during the life time (e.g. paper bags for a vacuum cleaner, paper filters for a coffee machine). There is a positive correlation between the energy consumption, cost of ownership and negative impact on environment. This state of the facts induced no incentive for producers to focalize efforts towards this direction. The awareness of the consumers on the environmental issues has put pressure on companies to reduce the energy consumption, combined with eco-labeling and smart marketing strategies. Also, the environmental load is different for the same quantity of energy consumed in different regions, depending on the its production origin (e.g., in US more than 70% of electricity comes from non-renewable resources, while in Switzerland this is less than 2% - source www.IAEA .org).

End-of-life

End-of-life has been by far the focus of the eco-design, although this stage counts in average for less than 10% of the life cycle environmental load (as opposed to use 50% or materials 25%). Generally, eco-designed products are designed considering the following end-of-life aspects:

- longer useful life (reusability)
- remanufacturability
- high recyclability
- potential for energy recovery.

This order is not always desirable, like it is the case of a product embedding new technologies which allow reducing the life cycle impact (e.g., it would be worse extending the lifetime of an old generation fridge with a high energy consumption than recycling and replacing

it with a new low energy consumption and CFC free – this may be true from an economic point of view too).

Recyclability is in most of the cases the most desirable characteristic of the products reaching the final disposal phase (end of last life). Beginning with the 70's recycling was performed for business, due to the large proportions of metals and precious metals. In the 90's the owner used to pay the recycler (recycling for environment), while since 2000 the producers have paid recyclers to treat the EOL products, which meanwhile became more recycling friendly.

Today, not only new products are affected by the global market, but also the second hand and the disposed ones. Technological, economic, geographical and legislative uncertainties make the task of optimizing for EOL very challenging. Eco-design encouraged optimizing products for disassembly, mainly due to the wide spread idea that disassembly plays an important role in the recycling strategy, academic research finding a reach ground for subjects, often pushed to the highest degree of worthlessness and unrealism. Reality, in the developed countries, shows that mechanical treatment (shredding, sorting) and smelting processes are dominating, given the high labor rates of manual disassembly and heterogeneity of the income flow of products to be recycled.

Under these circumstances, eco-design can help in designing products that are more robust with respect to the EOL treatment. In other words, regardless of the EOL treatments employed and geographical location, a high recyclability rate, economic efficiency and minimal impact on environment is the ultimate goal. Advances in the development of separation and sorting technologies favor the "design for non disassembly" approach (Ram et al. 1998) combined with the design for easy removal of the hazardous parts and substances before mechanical treatments.

3. ENVIRONMENTAL LEGISLATION

Environmental regulation plays a critical role in the process of implementing the environmental management within the companies, unlike some arguments stating that environmental protection measures are a cost burden for domestic firms and thus weaken their competitiveness on international markets. Global products face a greater challenge due to the heterogenic environmental legislation worldwide. Moreover, life cycle compliance with regulations is adding complexity to the product design, requiring the shift from the *cradle to grave* approach to the *cradle to cradle* (legislation will play a major role in making this a requirement and not an option). The list below is a selection of worldwide regulations that

producers have to comply with when designing and producing new products or retiring existing ones.

Australia

- The Hazardous Waste Act (1989, 1996)
- Environment Protection Act (1993)
- Used Packaging Materials (2007)

European Union

- End of Life of Vehicles (ELV 2000)
- Waste of Electrical and Electronic Equipment (WEEE 2003)
- Restriction Of The Use Of Certain Hazardous Substances In Electrical And Electronic Equipment (RoHS 2003)
- Energy Using Products (EuP 2005)
- Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH 2007)

USA

- Resource Conservation and Recovery Act (RCRA 1976)
- Clean Air Act (1990)
- California Electronic Waste Recycling Act (EWRA 2003) EOL
- California RoHS (2007)

Canada

- Ozone-depleting Substances (1998)
- Canadian Environmental Protection Act (CEPA 1999)
- Export and Import of Hazardous Waste and Hazardous Recyclable Material (2005)
- Prohibition of Certain Toxic Substances (2005)

Japan

- The Container and Packaging Recycling Law (CPRL 1997)
- The Electric Household Appliance Recycling Law (EHARL 2001)
- Automobile Recycling Law (2005)

China

- Cleaner Production Law (2003).

Pollution prevention and resources conservation have been among the top priorities targets of the environmental legislation. With respect to the life cycle stage they are addressing, most of

them are concerned with the end of life and with the production. Nonetheless, the indirect effect on the design is very strong, e.g. it may very difficult to achieve recycling targets established by WEEE or ELV type of regulations that are coming into force worldwide, without rethinking the design. Moreover, many of the targets are increased periodically, aiming eventually at 100% recyclability or so. The European Union, with the new EuP regulation, has stepped in the design process, with a tentative to formally establish foundations of eco-design practices. European Union is currently developing an Integrated Product Policy, that seeks to minimize the environmental degradation by looking at all phases of a products' life cycle and taking action where it is most effective, using measures such as economic instruments, substance bans, voluntary agreements, environmental labeling and product design guidelines. Life cycle thinking is the core of the system-based approach with the product design as the primary attention. This is also an attempt in avoiding the shift of the environmental burden from a stage of the life cycle to another. Although in its infancy, such initiatives in developing eco-design focused regulations may be followed by other non EU countries, like it was the case of WEEE.

4. ENVIRONMENTAL INNOVATION

Rennings (Rennings 2004) defines the *environmental innovation* as "new or modified techniques, processes practices, systems and products that avoid or reduce the environmental harm". This can take place on several levels, like science and technology:

- better properties (lighter, stronger, smarter, smaller)
- processing technology (molding, soldering).

Environmental innovations are integrated into new products by designers if the new products are aligned with the customers' needs or if new values can be created. Innovations optimizing environmental criteria in isolation, without meeting other voices of the customer (functionality, price to be paid) or cultural and regional differences may fail being diffused internationally or they can be a complete failure. E.g., fuel efficient diesel engines have a high adoption rate in Europe (high fuel prices), while being less popular in USA, where the fuel efficiency hasn't been an issue (fuel price is two times lower than in Europe), but rather the emissions which promoted the diffusion of the catalytic converters.

Besides the functional benefits, customers are not always aware of all the other values a product can offer (material-immaterial, present-future). Creating the need by increasing this awareness is a vehicle for the dissemination of environmental technologies.

It can be argued that environmental innovation may have hidden effects which are difficult to quantify. For example, the trend towards increased recycling and reuse of materials leads to innovations in the field of reverse logistic systems, which then becomes a rapidly growing industry. In contrast, clean production reduces the demand for material, energy and end-of-pipe-technologies, and thus reduces the demand for labor in these sectors. The net effect of clean production on employment is therefore uncertain (Pfeiffer 2001).

It is important to emphasize the role of the non-technological factors in the diffusion of the eco-innovations, like the double-externality (Beise and Rennings 2005), which inhibits companies' desire to invest in environmental innovations. When a company adopts new measures towards the improvement of the quality of the environment, the whole society benefits, and thus it is difficult for the innovator to appropriate the profits, while the cost is paid by the company alone.

A study of the European Commission (Tukker et al. 2006) revealed that food and drink, private transportation and housing (including furniture, appliances, room and water heating) are contributing to 70-80% of the environmental impact in the European Union, on a life cycle basis. Energy consumption, regardless of the life cycle stage, is a major contributing factor to the environmental damage and this is the reason why reducing energy consumption (through lower quality of energy services or by improved efficiency) has been the driver for many of the technological innovations.

An interesting aspect of the energy efficiency is the fact that unlike the technological advances that allowed the development of higher efficiency products and processes, the total energy consumption keeps growing although this happens at slower rates compared to the GDP growth, in the advanced economies, as shown in Figure 6. One possible explanation is the so called *rebound effect*. This has a *direct* effect by lowering the cost of ownership and thus stimulating consumer to use more products, or producer to make bigger products, and an *indirect* effect by channeling the income saved towards other products or services, or *economy wide* effects due to long-term changes in the economy (Dimitropoulos and Sorrell 2006; Herring and Roy 2007). Paradoxically, this may convey the message that energy efficiency may not

necessarily be the best solution to the energy saving or reduction of emissions. Nevertheless, according to (EIA 2007) the worldwide energy intensity will decline by 2.1 to 2.3% per year, until 2030. This is explained by the fact that in the advanced economies (e.g. OECD countries), there is a high penetration rate of modern appliances and motorized personal transportation equipment. The purchase of new energy consuming goods, should involve more often the replacement of old capital stock. The new stock is often more efficient than the equipment it replaces, resulting in a weaker link between income and energy demand.

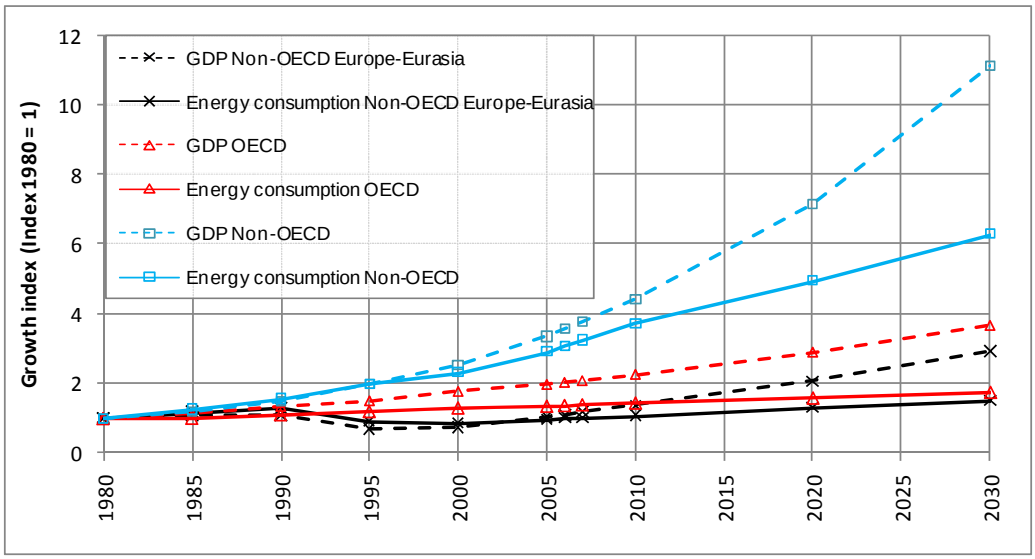

Figure 6 Energy consumption growth index compared to GDP (data from(EIA 2007))

Innovation should be addressed systematically in order to be reliable (Wynett et al. 2002) and this attitude should be considered for the eco-innovation as well.

5. ECO-DESIGN VALUE ALIGNMENT

5.1. Integrating of Eco-design into the Early Stages of Product Development

Globalization, *environmental legislation*, and *eco-innovation* are three contradictory aspects that are challenging the eco-design practices today. The first one is the result of the society's demand for more affordable products, being generally perceived as an obstacle or a worsening factor in the reduction of the life cycle environmental footprint of the produced goods. Eco-innovation is stimulated by the desire for a sustainable world, facing challenges of its own, while regulations turned out to be the only efficient way of dealing with the environmental issues.

Global product has been an approach to deal with the economic globalization, by trying to build "universal" products that satisfy the customers all over the world. Besides the trend for customized products, "one size fits all" type of eco-design tools are often prone to failures. This may be due to:

- different regional value chain structure
- different life cycle for the same product in different countries
- VOCs and their importance may vary geographically
- QFD may change with product versions
- environmental impact of the same product is different for various regions/countries.

There is a need for simple yet powerful approaches to eco-design which can deal with the aforementioned variations and regional differences during the early stages of the design. Moreover, there is a shift in the demand for greener products under a stronger price competition, and selling the right product, with the right features at the perceived value by the customers is critical. Product environmental performance over the life cycle (often reflected into the cost of ownership) is definitely one of the key factors that companies have to master. Nevertheless, unless correlated with the value offered to the customers, "green" as such will not sell. Eco-innovation is one of the keys to reduce the products' environmental burden.

The concepts proposed in this section try to respond to some of these challenges. They can be flown into the NPI process from the product definition phase and encourage eco-innovation. A brief example will be used to illustrate some of the tools, but comprehensive case studies are to be performed in order to validate their efficiency and applicability.

5.2. Philips' Environmental Programs

Market oriented companies, such as Philips, are aiming for the reduction of the environmental burden caused by the design of the product to achieve competitive advantage.

After the '73 global oil crisis, Philips initiated a first energy saving campaign. But they realized that reactive behavior to environmental problems is not very efficient. In 1991 Philips established its first environmental policy, followed by the environmental programs *Environmental policy* in 1994 and *Eco Vision* in 1998, and sustainability programs *Eco Vision II* in 2002 and *Eco Vision III* in 2006. From a case-by-case basis driven by single persons, eco-design has become a standard part of the product creation.

Table 2 Environmental programs at Philips

Program	Actions
1994-1998 *Environmental opportunity*	- focused on potential savings in the manufacturing and industrial operations - laid down the foundations of future environmental programs that will include development and marketing - *target*: release of a single Green Flagship product per *product division* per year
1998-2002 *EcoVision*	- full scale integration of eco-design into the product creation process - setting targets for percentages of eco-designed products - all BU were challenged to include eco-design on their projects and insert environmental requirements in their product's specifications - communication of the environmental performances to the outside world - use of LCA recommended to safeguard the life cycle principle - benchmarking activities to compare Philips products with competitors' - target: release of a single Green Flagship product per business unit per year
2002-2005 *EcoVision II*	- continue to improve the environmental performance in manufacturing, product design, purchasing - in addition it investigates the social performance of its operations and suppliers (health and safety) - eco-design performance no longer measured in % of products - the Maturity grid with levels from 0-10 is introduced to measure the maturity of eco-design as well as of purchasing activities
2006-2009 *EcoVision III*	- product improvements using the Green Focal Areas - process improvements

During 15 years of eco-design practices, Philips has transformed a non-added value process into an activity whose results are not only used to increase the market share, but also as part of the performance indicators for the management. Unlike the successful environmental programs, globalization (outsourcing of the manufacturing to China) still brings several challenges to their eco-design practices due to:

- Different cultural background:

- All people are equal (not in reality)
- How it should be and how it is
- Theory and practice - two different things
- Relationships prevail contracts
- Different culture of learning
- Nature is an enemy

- Different engineering and technologies
- Different environment and sustainability perception
- Communication is strongly affected due to the distance (R&D in Europe, manufacturing in China).

5.3. Integrating Eco-Design into the Product Development

Manufacturing Modeling Lab (MML) at Stanford has had a long tradition in teaching eco-design as part of the ME317 Design for Manufacturability course. The fruitful collaboration with Philips, and especially with the person who initiated their environmental programs, Prof. Ab Stevels, made the authors rethink some of the key tools taught, such that challenges like those discussed here could be considered and dealt with as soon as possible during the product development.

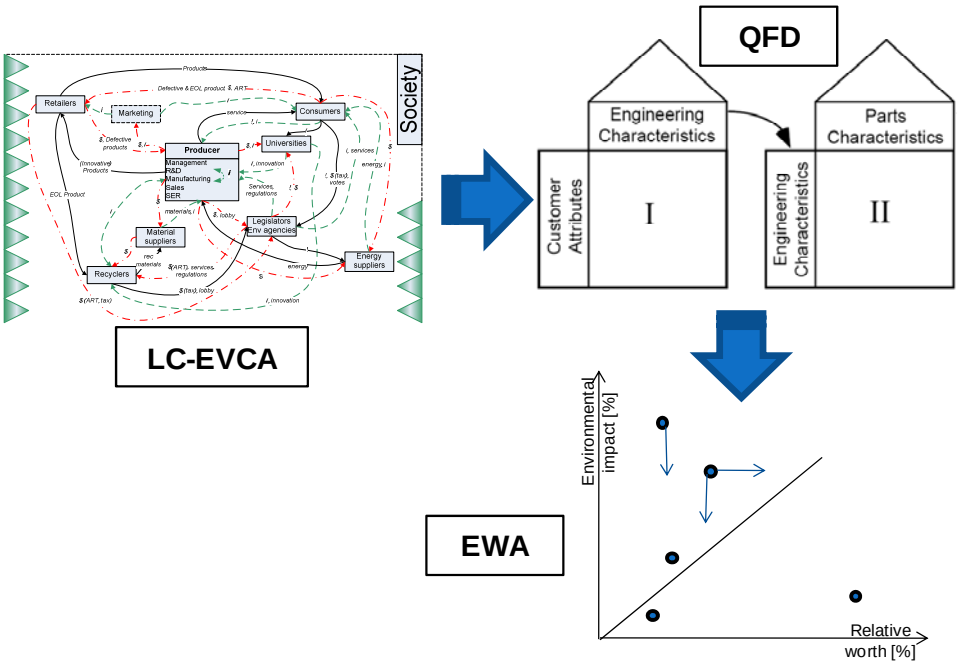

Figure 7 Eco-design value alignment steps

The next sections introduce a methodology seeking to facilitate the alignment of the eco-design value with the customer needs, whose key features are:

- *identifying* the players involved in the value chain, during the whole life cycle, and the relationship amongst them
- *finding* the key players susceptible to provide value in terms of improving the environmental performance as well as the perceived value of the product
- *prioritize* the product subsystems which are prone to environmental improvement in terms of value provided to the customer vs. environmental burden
- *use* this information to improve design and deliver high value products with low environmental impact.

A sequence of well established tools like *QFD*, and new ones - *Life cycle Environmental Value Chain Analysis* and *Environmental Worth Analysis* are employed having the ultimate goal to deliver new values to the customers under the most advantageous conditions for business and environment (Figure 7).

5.4. Life cycle Environmental Value Chain Analysis

Inspired by the Customer Value Chain Analysis (CVCA), Rose (Rose et al. 2001) introduced the concept of Environmental Value Chain Analysis (EVCA), to illustrate the value relationships between the groups implementing environmental improvement programs, with a focus on the end-of-life. Customer Value Chain Analysis seeks to identify pertinent customer and other stakeholders' interests, their value perceptions and the relationship between these parties in green product or process development projects (Ishii 2006). Hereafter this concept is further extended from a life cycle perspective, following the principle that sustainable design should concern the whole stages a product goes through, regardless the players involved in each of them. This concept will be called *Life Cycle Environmental Value Chain Analysis* (LC-EVCA). The three major types of flows in the LC-EVCA are *money*, *materials* and *(green) information* (Figure 8).

There are other factors beyond the technical ones affecting the eco-design practices and environmental decisions within companies. In most cases, these decisions relate to the corporate culture, image considerations and financial perspective of a company, traditionally considered business issues.

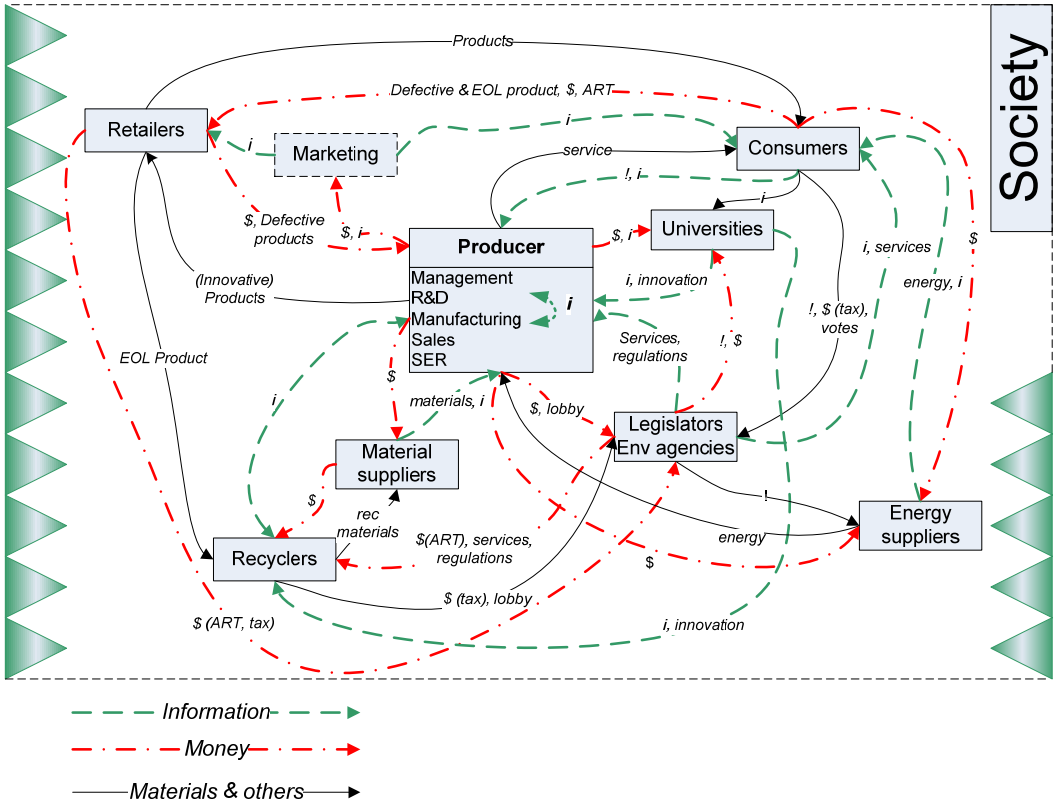

Figure 8 Life cycle Environmental Value Chain Analysis

Life Cycle Environmental Value Chain Analysis can help addressing these cultural and financial issues methodically through close examination of the flows between the players. The main flows are *information*, *money* and *materials*. The LC-EVCA includes these main players: producers, legislators and environmental agencies, consumers, retailers, material suppliers, recyclers, energy suppliers, universities and marketing (whether it is part of the company or third party) which play a crucial role in the alignment of the eco-values with the business.

Producers are interacting with all the players in the value chain. Environmental friendly products and technological innovation, in most of the cases happen because of the legal pressure from the *legislator*, *consumer* awareness, visionary internal environmental programs within companies or due to country specific conditions.

Legislators (governments, local authorities, EU parliament, environmental agencies, etc.) have played the most efficient role in forcing or encouraging both producers and consumers in using more rationally resources and in reducing emissions. The US Environmental Protection Agency (EPA) or the European Environment Agency (EEA) are major players in informing decision makers and proposing environmental legislation on one side, while being a window of

information for consumers. Legislators play a crucial role in dealing with the rebound effects discussed before.

Consumers are mostly responsible for the use phase of the products (consumption of energy and consumables) and the way they are discarded, but they also play an important role in influencing the environmental strategies of the producers. There are two issues with the energy using products: their consumption is predefined by the producers, but the use pattern belongs to the consumer. They share both the responsibility for the damages caused to the environment. At the EOL they want to get rid of the products in a convenient, free of cost way.

Recyclers consist of the collectors, processors, and distributors of discarded products, either disposing of waste or retrieving value from products and materials. Collection may be through retail or municipal infrastructure, through charitable donations, or through individual curbside pick-up. End-of-life processing include repair, servicing, remanufacturing, recycling through shredding with or without disassembly and disposal through incineration or landfill. Recyclers seek to minimize the costs and maximize the profits mostly by focusing on specific material or product streams. This should be aligned with characteristics of products to be treated (Rose, Ishii et al. 2001).

Energy suppliers tend to stimulate energy use as long as the profit depends on sales, participating negatively to the energy, resources and emission reduction. Nonetheless, legislators can play the role of a regulator, like it happened in California, where the decoupling innovative approach to utility regulation, made the profits no longer linked to simply increasing sales (Mufson 2007).

Retailers, in the traditional sales system (as opposed to direct sales, or built to order) decide what are the products and the brands they want to sell, based on strategies and reasons which may be different than the producers'.

Marketing, as a link between producers, consumers and retailers, plays role of aligning the new values proposed by the eco-designed products with the perceived value of green by the customers. An analysis of consumer attitude (Stevels 2001) shows that 20 to 30% of the consumers consider environment in their buying decisions, while the same amount don't care or have a negative perception (lower quality or higher price) (Figure 9).

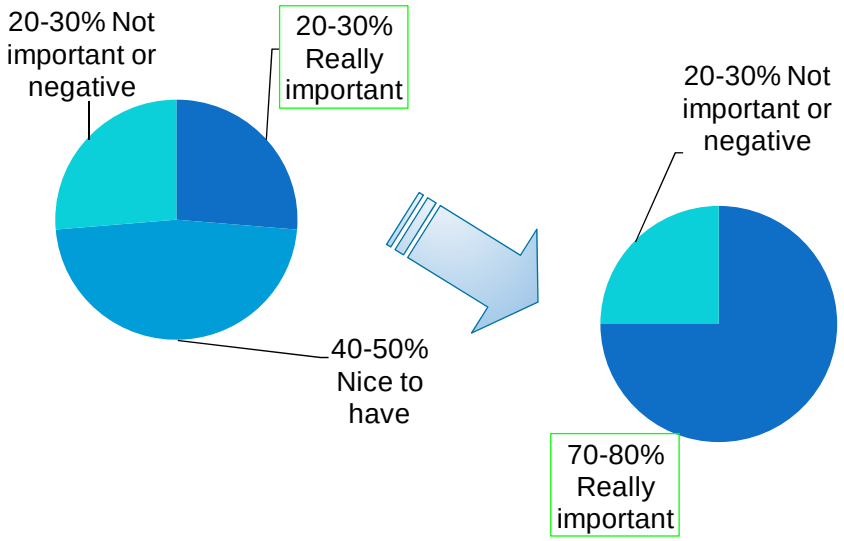

Figure 9 Importance of green in buying decisions as perceived by consumers worldwide

About half of the customers would choose a more environmental friendly product if they don't have to pay a premium for this. This category of consumers is the target of new strategies employed by companies that try to differentiate on the market from the competitors, by emphasizing other values eco-designed products would bring, and thus generating their migration in order to obtain a higher market share.

Universities are the link in the environmental value chain whose approach has been more idealistic and ignoring in many cases the economic reality, the real customers in the value chain together with their needs. There are several essential differences between the industry and academic approach to eco-design, i.e. creating value vs. reducing environmental load, relative vs. absolute measuring of performance, integrating environment into product creation vs. separate green projects, etc. Also, the communication of the results is done in different ways: industry places the benefits for the consumer first, while academic researches addresses the environment in the first place. Nevertheless, universities, through their relative independence from the economic performance, can afford the change of priorities and approach the environmental problems in a holistic manner. Ultimately from this, both society and industry will benefit, first by being objectively informed of what is going on independently of economic interests and the latter by transforming and transferring this knowledge into economically viable environmental friendly products and technologies.

The information flow in the LC-EVCA

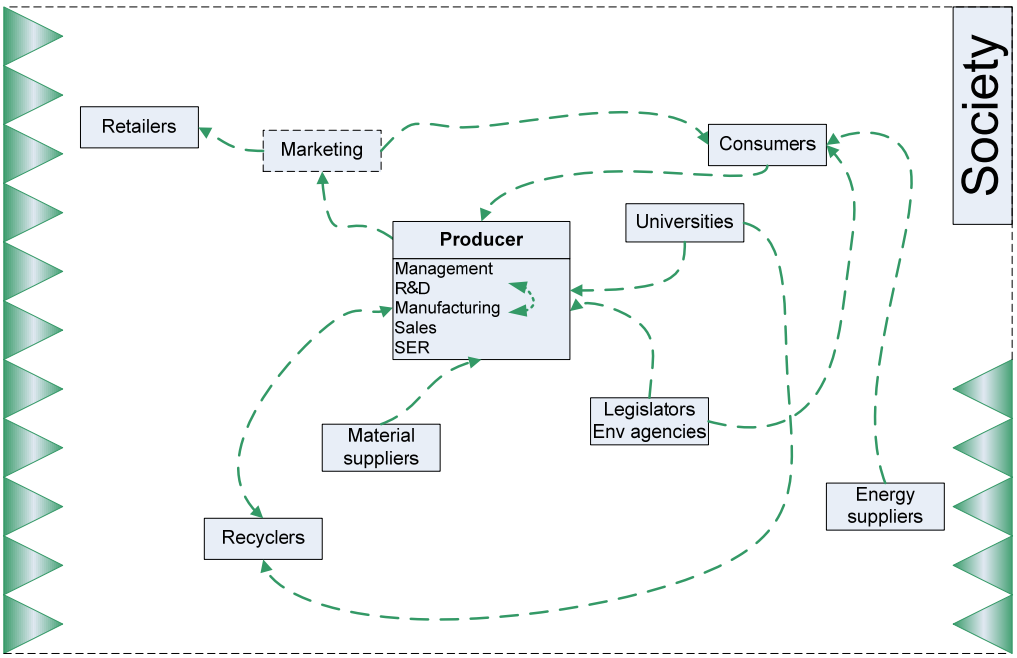

Figure 10 Information flow in LC-EVCA

If exploited properly, from the standpoint of the eco-design, the information flow in the LC-EVCA provides companies with the necessary knowledge needed to successfully align the environmental improvements with the business. That is why it will be discussed in more detail.

Organizations within the same industrial sector and operating under similar regulatory and market conditions, apply eco-design taking two different approaches: *i) based on continuous improvement* and *ii) driven by the legislation* (Pascual and Stevels 2005).

While companies falling under the second category are reactive, using only a small part of the information in the LC-EVCA (coming from the legislators), the first category is taking advantage of the whole information flow not only to improve the environmental performance of their goods, but to capture unexpressed or immaterial customer needs otherwise unrevealed.

Producers are the center of life cycle information coming from the products they put on the market. Making better products means closing the information loops from the whole life cycle stages: beginning of life (BOL) which happens before the product reaches the market, the middle of life (MOL, use) and the end-of-life (EOL). This is done to enable the seamless flow, tracing and updating of information about a product, after its delivery to the customer and up to its final destiny and back to the designer and producer. Figure 10 shows the main flows of information in

the LC-EVCA. PROMISE project (Bufardi et al. 2004) targets the long term, to allow information flow management to go beyond the customer, to close the product life cycle information loops, and to enable the seamless e-transformation of product life cycle information to knowledge. One of the main consequences of this approach is that designers will be able to exploit expertise and know-how of the other players in the products life cycle and thus improve product designs towards product life cycle quality goals. Although the approach considered in PROMISE heavily involves wireless technologies like RFID and PEID, until this technology will be proven and cost-effective fort this type of application, data about the life cycle can be collected in less sophisticated ways like good communication strategies between design and manufacturing (or suppliers), customer surveys, user centered studies, follow-up of the EOL treatments, etc.

5.5. Quality Function Deployment

Quality Function Deployment (QFD) is a product development tool that acts as a set of planning and communication routines. It focuses and coordinates commonly used product development processes (benchmarking, market research, etc.). QFD is an approach to product development that originated in Mitsubishi's Kobe shipyards in 1971 and during the 1970's and the early 1980's, a variety of Japanese companies used QFD to enhance their product development effectiveness.

QFD in its full form consists of four different matrices. Our approach makes use of the first two matrices, shown on the right side of Figure 7. These matrices allow the product development team to relate customer-weighted system-level VOCs to the system level engineering metrics (EMs), using a weighted mapping scheme from 1 to 10. QFD House II maps the engineering metrics to parts characteristics.

5.6. Environmental Worth Analysis

The *ecovalue* concept introduced in (Pascual and Stevels 2006) is a means of linking the environmental performance of a product to the business aspects (price). The tool helps decision makers in matching product design alternatives with various consumer groups, based on the principle that different people prioritize differently between environmental and financial matters. Although the concept is useful for product comparison, it doesn’t capture the internal structure of the individual product, as opposed to the tools introduced here.

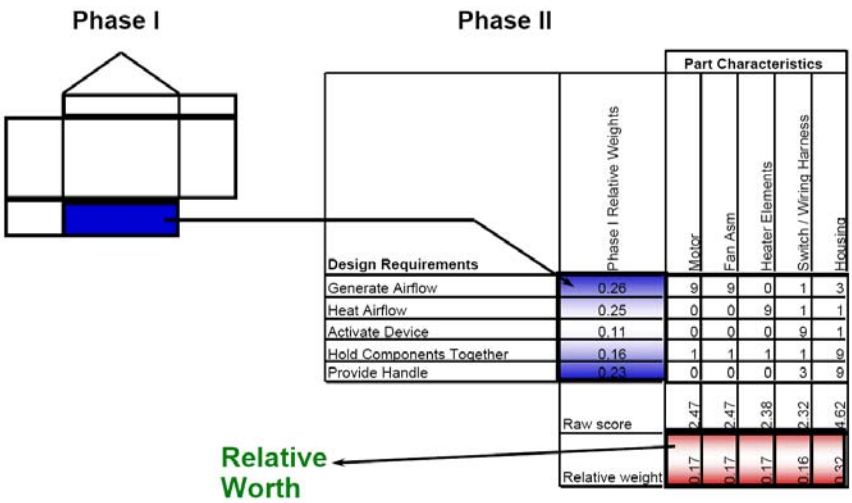

Figure 11 Determining the relative worth using QFD

Tanaka (Tanaka 1989) developed the Cost/Worth analysis method, which compares the relative component costs to the estimated worth. In Tanaka's method, the relative worth of each component is determined by a qualitative evaluation by the design team. Martin et al. (Martin et al. 1998) used the output from QFD Phase II to eliminate the more subjective evaluation used in Tanaka's method (Figure 11).

Besides the functional aspects, the worth of a product can also capture the *emotional* (feel good, less fear when using the product) and *immaterial* (easier to use, more convenient, more fun) values. These values are difficult to quantify, but once identified, product developers can differentiate on the market by responding with products that satisfy them too. Environment friendly products embed such values, and leveraging the engineering metrics to improve the customer's perception of the product value (worth) is one of the keys for the successful alignment of the eco-designed products with the business.

Plotting the environmental impact of the subsystems/parts of a system/product against their worth is a simple, yet efficient way to detect the inefficiencies within the product. Inefficiencies are those subsystems/parts creating a high environmental impact, while having small contribution to fulfilling the VOCs. There are two possible types of graphical representations:

1. A matrix type with absolute values (Figure 12)
2. Relative values plot (Figure 13).

The matrix type EWA

For each of the subsystems/parts, the environmental impact is calculated using one of the life cycle assessment (LCA) methods that are able to express environmental impact using a single aggregated indicator (Ecoindicator 99, IMPACT2000+, etc.), which are usually expressed in Points (Pt). These values, are normalized on a [0, 1] scale and plotted on the vertical axis.

The worth of the subsystems/parts is taken from the output of QFD II. The raw score is normalized as well and plotted on the horizontal axis.

Four situations are envisaged, represented by the four regions in Figure 12:

I. *High environmental impact / High value for customer*

Parts from this region are required to fulfill the VOCs, but they also induce a high cost to environment. Making a parallelism with the BCG matrix from portfolio management, these are the “stars”, whose environmental impact should be reduced, and thus move them in the region II (represented by the down arrow).

II. *Low environmental impact / High value for customer*

This is the ideal region (the “cows”) which contains the parts offering high value to the customers with small cost to the environment. A green design would have most of the parts in this region.

III. *Low environmental impact / Low value for customer*

This region contains the “question marks”, which are the parts with a low worth but with a low environmental impact too. They are somehow neutral, and there are two possible actions that can be envisaged: increase their worth and thus transform them in “cows” (right arrow), or try to eliminate them (left arrow)

IV. *High environmental impact / Low value for customer*

Parts situated in this region have a high environmental impact, but a small worth. These are “dogs” that ideally, one would try to eliminate (up arrow), since their role in satisfying the VOCs is minimal.

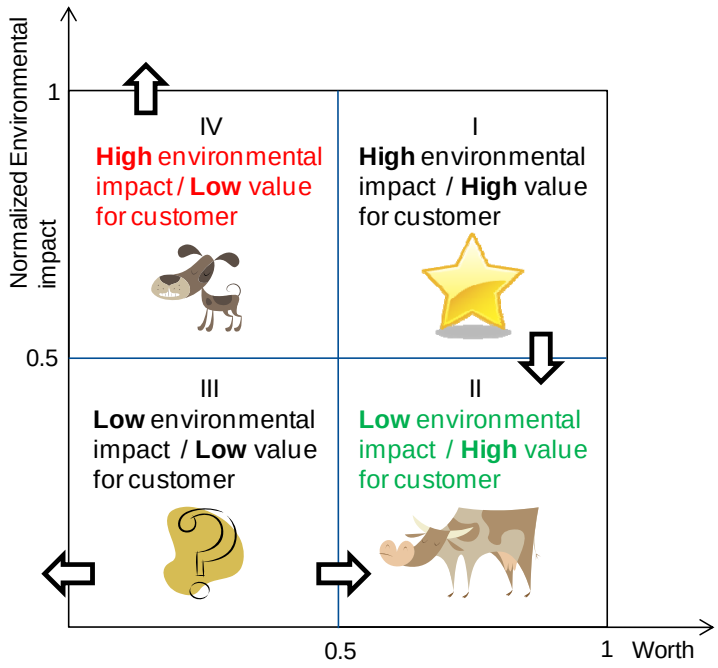

Figure 12 Environmental Worth Analysis

The relative values plot

By transforming the absolute values for the environmental impact and worth in relative measures (% of the total environmental impact and worth respectively), one can plot a chart like the one in Figure 13.

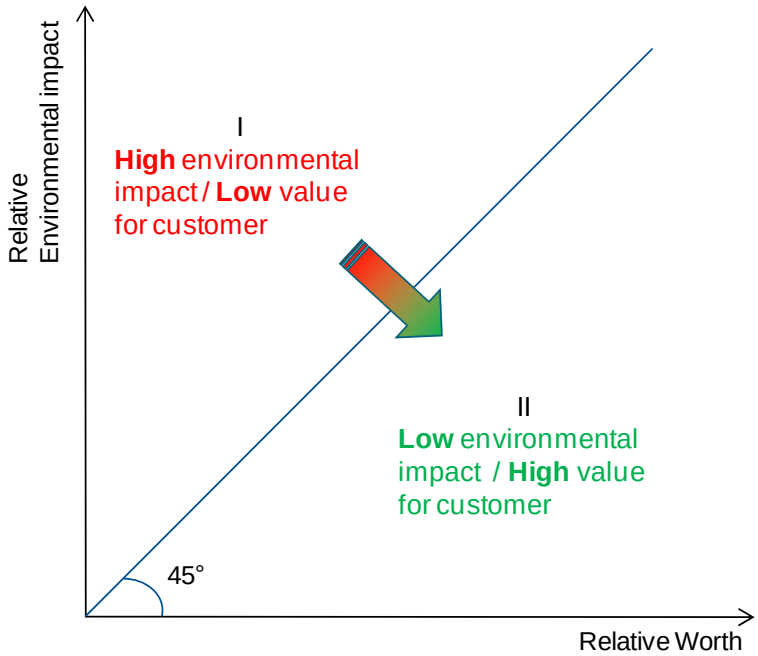

Figure 13 EWA relative plot

The plot area is divided in two regions by the bisector: *high environmental impact/ low value for customer* and l*ow environmental impact/ high value for customer*. This plot can be seen as a simplified version of the matrix type EWA. Eco-design has to consider at least the subsystem/parts that are above the bisector. There are two possible actions that can be taken:

- Move these parts down on the chart by decreasing the environmental impacts
- Move them to the right by increasing their worth.

5.7. An Illustrative Example

Let us consider the design of a canister vacuum cleaner whose QFD I and II are shown in Figure 14 and Figure 15 respectively. For simplicity, in QFD II, functional modules replace the parts.

		Engineering Metrics							
Customer Requirements	Customer Weights	Overall Size	Weight	Suction power	Noise level	Dust container volume	Power cable length	Motor power	Time to clean VC/change filte
Easy handling/use	3	9	9				1		
Good suction/dirt pick-up	9	1		9		3		9	
Quiet operation/Low noise	3			3	9			1	
Fast cleaning	9	1	3	9		3	3	3	3
Long working range	1						9		
Energy efficient	3							9	
Easy to maintain/clean	9			3		3			9
Easy storage	1	9	9						
	Raw score	54	63	198	27	81	39	138	108
	Relative Weight	8%	9%	28%	4%	11%	6%	19%	15%

Figure 14 QFD I of a canister vacuum cleaner

		Part Characteristics					
Engineering Metrics	Phase I Relative Weights	Controls	Motor	Power cord	Dust storage	Filters	Housing
Overall Size	8%	1	9	3	3	3	9
Weight	9%	1	9	3	3	3	9
Suction power	28%		1		9	3	
Noise level	4%		9				9
Dust container volume	11%				9		3
Power cable length	6%			9			
Motor power	19%		9				
Time to clean VC/change filte	15%				9	9	3
	Raw score	0.2	3.9	1.0	5.4	2.7	2.6
	Relative Weight	1%	24%	6%	34%	17%	17%

Figure 15 QFD II of a canister vacuum cleaner

This example analyzes a simple paper bag type vacuum cleaner with a motor power of 1800W and offering max 350 Airwatts suction power. It was also assumed an average lifetime of 10 years, 30 minutes use/week, and change of the paper bag each month. Using the Simapro® software with EcoIndicator99 LCA method (Hierarchist perspective and average weighting set) we obtained for each module the single environmental impact indicator measured in mPt. Figure 16 shows the relative worth (form QFD II) vs. relative environmental impact while the matrix EWA is plotted in Figure 17. The modules *dust storage*, *controls* and *motor* are above the diagonal and thus they should be the focus of analysis.

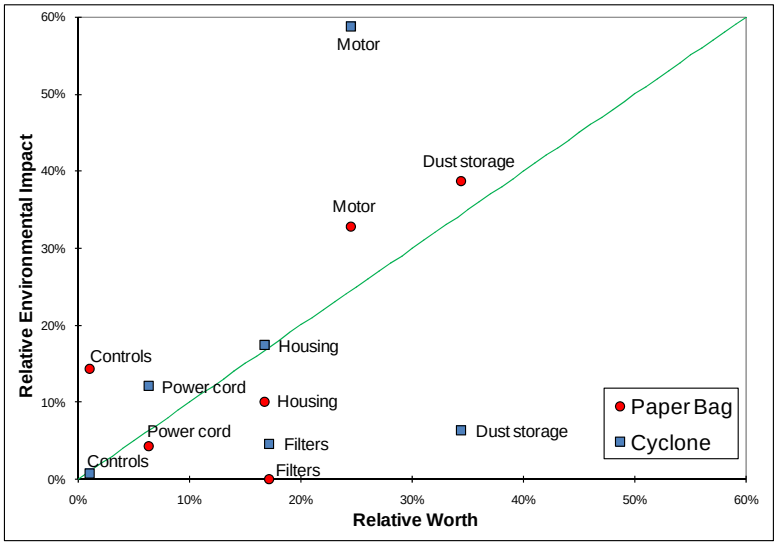

Figure 16 The relative EWA of the vacuum cleaners

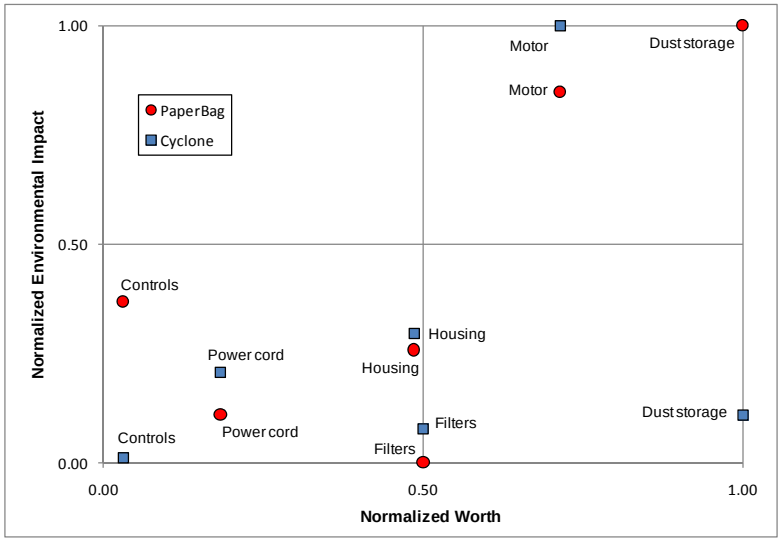

Figure 17 The matrix EWA of the vacuum cleaners

A redesigned vacuum cleaner that stores dust using an innovative solution for filtering – the cyclone in a plastic bin – gets rid of the use of consumables (paper bags), requires a reduced motor power for the same average amount of Airwatts (constant suction power vs. decreasing power due to the clogging of the paper bag) and thus less electricity used and fewer control and safety devices. Plotting the two concepts on the same chart points out that dust storage and controls moved down under the diagonal, while surprisingly the motor shifted up, although its overall life cycle impact decreased. This is a common drawback of the relative representations on one hand. On the other hand, the motor would be shifted to the right side of the chart if, for the new design, the relations between EMs and parts in QFD II were updated reflect the stronger relation between the motor and the suction power. But the most important conclusion here is that in a next step, the motor should be the focus of the improvement.

The main conclusion inferred from this example is that the EWA (iteratively) helps prioritize the candidates for improvement based on the alignment of the environmental impact and the perceived worth by the customers.

6. CONCLUSION

This work documents the analysis, from an environmental point of view, of three challenges companies are facing in the 21st century: globalization, legislation and innovation. Functionality is not the only attribute products must satisfy. Consumers are more knowledgeable about the products they buy and they seek environment friendly products and services. Companies who understood these needs are gaining market advantage. Customers must also replace old and actively pursue the 3 R's: reduce, reuse, and recycle. Environmental legislation that is coming in force globally accelerates good environmental practices on producers as well as consumers. The alignment of the environmental values of producers, consumers, and regional regulators is one of the keys to a sustainable world. The collaboration between Stanford University and Delft University culminated in an integrated approach to help companies align their values with the consumers. The triad, LC-EVCA–QFD–EWA, is a simple approach that helps identifying the customers involved during the whole life cycle and translating them to product and life-cycle process design, with the ultimate goal of designing better and greener products.

Further research will investigate how environmental improvement affects the life cycle cost, with the aim of finding the right trade-off between the two aspects. Under the collaboration with Philips, MML will undertake several case studies. They aim at revealing successes and failures

due to eco-design practices early in the PD in the context described in this work, and how tools like LC-EVCA–QFD–EWA could have improved products and customer satisfaction.

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