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Essential perspectives for Design for Environment;

Experiences from the electronics industry

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Abstract: Consolidation of knowledge, information and experiences in application of Design for Environment principles is done at various levels, ranging from easy to understand slogans to design guidelines, and even to tailor-made solutions. This brings about that dissemination of this knowledge should be done taking carefully the intended audience and relevant contexts into account– especially when dissemination is done in the form of 'principles', which are usually presented without context at all. It is discussed in this paper how interpretations of consolidating principles can lead to misinterpretations and even counterproductive actions. At least three principles can be identified that should be taken into account when disseminating DFE knowledge, discussing 1) different perspectives of what is environmentally friendly, 2) the life-cycle perspective, and 3) the integration of environmental and economical considerations.

Keywords: green engineering, ecodesign, design for environment, industrial application, life cycle assessment.

1. Introduction

Design for Environment (DFE) is widely understood among scholars and industrial practitioners to be the integration of environmental considerations into product and process design. Design for Environment is to ensure that all relevant and ascertainable environmental considerations and constraints are integrated into a firm's product realization (design) process (Allenby, 1994). Design for Environment, also known as environmentally conscious design and manufacturing or ecodesign, emerged as a phenomenon proposed and researched by academic scholars in the early 1990s, and has since then both in academia and industry found practitioners and proponents. Since the early days of DFE, like in many other science disciplines, there has always been a drive to consolidate information and knowledge in the form of guidelines. On the one hand, this is often done to get a basic idea or concept across to the general public. In the environmental field, basic ‘principles’ like Reduce, Reuse, Recycle (RRR), and Pollution Prevention Pays (PPP) are among the highest levels of abstraction, with a clear need to capture an elementary idea into a 'catchy' acronym. Such principles aim at spreading a generic concept or application. In order to make them more practical and easy to implement, they are often elaborated at a less abstract level, where one finds rules of thumb, and lists of guidelines. In fact, that is how, in the early days of ecodesign, information about how to design and manufacture environmentally friendly products was disseminated. Early ecodesign manuals present tools and methods targeted at a broad audience. Already at this level of environmental awareness and need for Design for Environment activities, it should be realised that a possible drawback of consolidation of information is the risk that context and application specific information may get lost.

Since these early days of DFE, companies have moved forward, have gotten acquainted with environmental issues, have started with pilot studies, have learned to pick the low hanging fruit, and have often learned to distinguish between issues to be dealt with at department level (such as proper documentation, relatively simple mechanical and electrical improvements, basic design and engineering issues) and those to be tackled at a company level (such as legislative issues, green sales & marketing, green supply chain management and various (other) external value chain topics such as including stakeholder and shareholder interests. Table 1 is proposed to indicate that the level of consolidation of information has changed as well, as this depends on the people that need to be involved, their level of awareness, resulting in more dedicated and tailor made communication tools necessary for bringing information across.

Maturity level of awareness	People involved	Level of generalness	Typically necessary communication tools
Relatively ignorant, need to be introduced and/or convinced, did perhaps some initial project	Personal to department level	Generic solutions and understanding	General principles, slogans.
Have been introduced, are moving forward with environmental issues, still deal with some elementary problems	Department to company level	Solutions and understanding tailor-made to the industry	Checklists, guidelines, examples of best practices
Have all the procedures in place, have considerable experience, have recurring problems with embedding environmental issues in the organisation and its value chain	Company to chain level	Solutions and understanding tailor-made to products and processes	Customised tools, databases, including information of the company’s internal and external value chain, experience

Table 1: Three maturity levels of environmental awareness

At the same time, design for environment as a scientific (sub)discipline has evolved as well, which has led to an increasing amount of relevant information and knowledge, that together with maturing competencies and experiences of companies, resulted in a third awareness maturity level. Here, one is beyond accepting the chief learning experiences and implementing basic structures and idea, and is ready for real operationalisation and exploitation of information and knowledge. However, at this stage one also fully encounters the need for balancing environmental criteria with traditional business criteria.

As both science and practice of green design and engineering evolved, the contextual applications for this science evolved as well. But as still large communities remain for which this insight is relatively new as well, the spread of 'level of sophistication of information' increases as well. Whereas in the early days of design for environment, most companies were found at the first level, at present, companies are to be found at all three levels indicated in Table 1; on the one hand, there are still companies that need to be introduced and/or convinced concerning product-related environmental threats and opportunities, other companies are very proactive and are in the forefront of not only implementing design for environment but also of exploiting the opportunities that they find, or create themselves.

This means that the way any meaningful information (which includes any type of consolidated information, be it in the form of principles, checklists, guidelines, examples of best practice, tools, databases, or management systems) needs to be offered depends greatly on the level of sophistication of the intended audience. At least one thing is clear: the higher the level of 'maturity' in environmental awareness, the more customised consolidated information will have to be. This is also where one reaches the borders of science -- at some stage customisation of knowledge will start to become consultancy rather than science.

Perhaps it is for this reason that in academic research, no matter whether the focus of research attention was on end-of-life issues, broader ecodesign methodology, or other green value chain topics, there is and always has been little research attention for customisation of ecodesign or green management strategies. Existing signs of customisation of ecodesign knowledge are mostly still a general, industry-wide or geographically dependent, level. Attempts to research customisation of ecodesign knowledge within an industry branch are virtually non-existent. Nevertheless, it is very likely that company-specific factors determine to a large extent the appropriateness and acceptance of ecodesign strategies. For example: in the electronics industry, established multinationals like Sony or Matsushita attribute a different weight to communication of environmental performance than, say, local Asian manufacturers. In the same way, given the legal system, North American companies deal differently with claims about environmental performance than the electronics industry in the European Union. Consequently, the identification of clusters of companies in order to characterise – in this case -- the electronics industry, representing similar backgrounds and attitudes towards environmental issues, could prove meaningful. Such clusters will include 'value' companies, who are interested in superior environmental performance though as part of many aspects in which they want to be superior. It could be that their strategy is one of risk management, avoiding bad press, while at the same time trying to maintain a high level of environmental performance. One of their characteristics is the pro-active behaviour towards environmental legislation, teaming up in branch organisations and active lobbying. A second cluster could include companies with similar objectives but with rather defensive strategies, companies with aggressive marketing and pricing strategies, less fundamental research, that are less proactive towards cooperation, sign agreements late, etc. There are also niche players, that operate in limited segments of the market, for example selling only high-end products, that may not even reach end-of-life, or at least have a very long lifespan and get handed over to 2nd, 3rd users, collectors etc. These have a very strong value proposition to customers, and their strategy is likely to avoid interference between environmental issues and their main value propositions. A fourth cluster could be local Asian manufacturers with little visibility in the international press, that will address environmental issues in terms of regulatory requirements only; price fighting rather than superior quality is the business they are in (which is in some aspects a sensible ecodesign strategy), and they will therefore benefit from customised ecodesign strategies. A fifth cluster could address so-called 'low visibility giants'; companies that extensively manufacture (and design) electronics products, in particular the inside, but mainly as outsourced manufacturing for value companies in particular. Their role is very interesting because it is potentially very powerful. A variation of this cluster includes companies that manufacturing subassemblies and components for application in products for brands worldwide.

In the field of Design for Environment, it can be argued that the ISO 14062 technical report is the manifestation of the border between academic attempts to generalise knowledge relevant for industry, and customisation of such information for individual companies. ISO 14062 is the result of academic and industrial experiences and cooperation, and gives an outline of chapters that discuss strategic issues (company strategy, programs and priority, supply chain items, design strategy), organisational issues (role of senior management, integration and involvement of business functions), and development process issues (such as idea generation, conceptual design, detailed design and market launch) (Stevels and Boks, 2003). Although still general in nature (ISO 14062 is suitable for interpretation by a wide range of companies), any further detailing of the issues mentioned will imply consideration of such detailed company internal information that it can no longer be called science.

2. Aim of this paper

Based on the observations discussed above, this paper departs from the hypothesis that consolidation of information, as has been common in early days of ecodesign activities, and consequent lack of appropriate customisation of environmental information, may lead to counterproductive actions in practice; a practice with a much larger spread of environmental awareness than a decade ago. This hypothesis will be further explored by a literature review in section 3 that aims to describe current implementation levels in industry, in particular the electronics industry. In section 4, three basic principles are proposed as truly generic. Through discussion and the use of examples, it is motivated why application of these principles, that tend to be overlooked, will reduce the risk counterproductive actions in the field of Design for Environment. In section 5, conclusions are summarised, and a future outlook on high potential research avenues is presented.

3. Literature on getting the DFE message across

This issue of communication of knowledge – rather than the creation of knowledge itself – is now slowly gaining interest in the environmentally conscious design and manufacturing community. Especially in the electronics industry, research efforts appear mostly to concentrate on finding solutions for DFE implementation rather than on identifying what the real problems are. In fact this means that these research efforts are creating problems rather than finding solutions. A literature survey by Pascual and Boks (2003), encompassing about 850 DFE-related conference papers in the 1998-2002 period, shows that 67% of all papers published by academia focus on tools and methods for DFE, while only 7% is devoted to surveying existing knowledge, and to the identification of societal phenomena and external factors that cause the need for DFE. In papers originating from industry, over 83% of the papers is devoted to technicalites and tool support, whereas a mere 8% addresses issues like roadmapping, green idea generation, green communication and strategic issues. Recent literature has discussed this discrepancy -- though often as a side issue. A number of publications have addressed criteria and enablers for improving the implementation of DFE in companies through improving communication (recent contributions include for example Mathieux et al. (2002), Handfield et al. (2001), Johansson (2000), Charter et al. (2002) and Tukker et al. (2001). Some of these have to some extent addressed causes why a combination of people, tools and an apparent goal do often not bring the envisaged success. For example, Mathieux et al. describe an analysis of 24 ecodesign studies in the European electronics industry, carried within the EU's Ecolife project. This study concludes that a number of principles for successful implementation of ecodesign are in general ill-addressed. These include 1) an excessive focus on complex tools and methods, also in cases where they are not needed, 2) a lack of life-cycle thinking caused by organisational complexities, 3) the cooperation between actors, and 4) the (industrial) context in which ecodesign activities are or should be embedded. Similarly, based on a large European survey, Tukker et al. came across a number of similar pitfalls in method development, including 1) lack of testing in practice, 2) lack of communication, exchange of experience and mutual cross-fertilisation, 3) lack of clear target groups and 4) lack of simplicity. In this study, also a number of suggestions for improving application of best-practice ecodesign are given. In the same line, Handfield et al. present a number of findings based on a large survey of Environmentally Responsible Manufacturing (ERM) practices in industry. These findings include the fact that 1) ERM-related activities are mainly material-related and defined primarily in terms of recyclability, 2) that conventional ERM tools are poorly understood and rarely used, and 3) that in general a large gap exists between those that promote and support ERM activities and those that have to execute them, in particular designers. Cramer and Stevels (2001) discuss a number of conditions for success of ecodesign implementation processes that extend beyond products and processes and even the company. These include 1) the organisation's culture, 2) business conditions such as profitability and market share, 3) the degree of environmental influence exerted by external stakeholders, 4) the available room to maneuver in relation to degrees of freedom for (re)design, and 5) the degree to which environmental issues can be used to gain a competitive edge.

The electronics industry

The electronics industry is a typical example of an industry that has moved into the third maturity level of awareness over the past decade. As it is a typical end product oriented industry, it has moved relatively quickly from being an end-of-pipe industry, and later a process-oriented industry, to a product-oriented industry, and bears as such the characteristics of product-oriented environmental management. Kolk (2000) attributes a number of characteristics to this type of industry, including changes to be made in the entire product chain, a focus on product as well as process design, the need for a clear policy and a highly integrated place of environmental management in the organisation. The main environmental impacts in this industry are caused by production and by energy consumption in the use phase; the environmental effects of processes other than material production are for instance low. This makes already that some proposed 'general' principles for green design and manufacturing are more relevant than others. For example, the twelve Principles of Green Engineering as proposed by Anastas and Zimmerman (2003), are not equally important or relevant for this industry -- although they argue that '...these would not be principles... [if they are not] ...applicable, effective and appropriate across several engineering disciplines'. It could even be stated that application could lead to counterproductive results in a number of cases as will be explained in this article.

4. Tailor made principles for Design for Environment in the electronics industry

To facilitate the discussion which principles would truly be generic and what environmental information needs customization, in this section three principles are proposed which both possess a generic truth and have the potential to contribute significantly to successful dissemination of Design for Environment knowledge into businesses. The basic principles are

- Only when including <u>different perspectives of green</u> that exist among different stakeholder, a design or engineering activity can be truly environmentally conscious (4.1).
- In all design and engineering activities, especially those targeted at environmental improvements, the <u>life cycle perspective</u> should be kept, taking into account sufficiently wide system boundaries (4.2).
- Design for Environment has a <u>much wider focus than just environment</u>, which can be and should be exploited (4.3).

In the subsequent sections, it will be motivated that these principles, which are easily overlooked in research topics or DFE projects focusing on a distinct aspect of a product's life cycle, can be understood to have a cross-functional, reflexive nature in the sense that they become relevant in all aspect of Design for Environment.

4.1. The different perspectives of what is green

The question ‘what is environmentally friendly?’ or ‘what is green?’ greatly depends on the different perceptions of the environment among the different stakeholders involved. In general, at least three types of ‘greenness’ can be observed.

Scientific green – In science, Life Cycle Assessment (LCA) is often regarded as ‘the most objective’ way to determine the environmental impact of products, processes and systems, as it seeks to examine the complete environmental profile throughout the full life cycle and includes for example electricity generation, infrastructure and other factors which cannot directly be influenced by the designer or industry. LCA scores are usually solely based on emissions and can therefore not always accurately describe the product end-of-life stage, as there are other aspects of environmental burden to be considered as well, in particular the resource perspective and the potential toxicity perspective – for which also descriptive models exist that are however less known. Not properly addressing all environmental aspects (by for example limiting analysis to LCA only) may lead to sub optimal solutions, such as for example in European lawmaking (Stevels and Boks, 2002). It also may prevent taking a proper life-cycle perspective, as is further illustrated in section 4.2. These and other objections against viewing LCA as a panacea for ecodesign are acknowledged by a variety of scholars, mainly by designers such as in Sherwin and Bhamra (1999), Simon et al. (2000), but also within the LCA community, such as by Guinee et al. (2004). Among the objections put forward are a lack of system perspective, the sole focus on product characteristics and consequent lack of inclusion of market mechanisms or social considerations, lack of inclusion of secondary effects on technological development, it’s comparative nature and the fact that it’s true application potential only emerges after detailed design has been done.

Government green -- Governmental Green strongly depends on a variety of factors like population density, the availability of energy sources, the geographical position (near the sea, mountains), the availability of landfill sites and/or incineration capacity and the status of the economy. Such circumstances determine the priority of items on the government agenda and do not always necessarily reflect the same order as they would have been if based solely on scientific arguments. They also include issues, which citizens (the voting public) regard as important for maintaining or improving quality of life or which are associated with emotions that perhaps cannot be substantiated by (LCA-based) scientific back-up, such as reduction of landfill sites, recycling issues and phasing out of (perceived) hazardous materials such as PVC.

Customer green – Green perceptions of the general public are strongly linked to emotions. Particularly environmental issues related to Health and Safety (and therefore potential toxicity) score high, resources are a mere long-term issue and therefore score low, emissions generally score medium. There is also a relation with events, for instance when energy taxes are raised, energy issues score high, when incidents occur with toxicity/food safety, the toxicity discussion flags up. When shortages of materials or of fuels occur, the resource aspect takes over. The seven archetypes for environmental consumer orientation that will be discussed in section 4.3 of this article are a good example of how ‘customer green’ can be incorporated in company strategies.

4.2. The life cycle perspective

In section 4.1 it was indicated that in science, Life Cycle Assessment (LCA) is often regarded as 'the most objective' way to determine the environmental impact of products, processes and systems. LCA seeks to examine the complete environmental profile throughout the full life cycle. This in theory provides a means to keep a full life cycle perspective.

On the other hand however, balancing and validation methods should be available which allow to account for this properly; but although the LCA community has been putting great efforts into constructing databases with reliable environmental impact information, disagreement on how to attribute environmental impacts to emissions in an accurate, well quantified way, continues to maintain the absence of a standard LCA method that is beyond discussion. As long as this situation persists, it might be best to consider a simplified approach by addressing the three main environmental aspects on separate entities; in order to balance different environmental dimensions and the stakeholder perspective in environmental legislation/regulation a number of equations have been proposed by Stevels and Boks (2002), describing environmental impact of products or product categories in terms that reflect both the resource (depletion) perspective and the emissions perspective, as well as the potential toxicity perspective. By weighing these with appropriate social priority factors and normalisation constants, the equations cannot only be used to evaluate the effect of environmental regulation initiatives but also to simplify environmental information (an important issue in European Integrated Product Policy legislation) and for balancing a variety of recommendable design avenues.

But even when a full life cycle perspective is taken, regardless of the method used, still environmental dilemmas will persist. This can be illustrated by discussing a number of environmental dilemmas that continue to exist in the electronics industry because of their conflicting effects for the above-mentioned three main environmental impacts, see Table 2.

Env. dimension / Issue	Emissions	Resources	Potential Toxicity
Replacing plastics by metals	- (more energy needed for production)	+ (recycling becomes easier)	+ (less additives needed)
Lead-free solder	- (more energy needed for process)	- (use more source resources)	+ (lead eliminated)
Elimination of flame retardants	- (more production energy)	- (more material needed)	+ (less potential toxicity)

Table 2: **Example of Environmental dilemmas**

- Replacing plastics by metals could be a design solution for fulfilling recyclability targets of up to 85%, as required by the WEEE directive in the European Union. Although recycling will become easier, and less additives will be needed that could pose an environmental problem in terms of potential toxicity, it would in many cases also mean higher emissions, as producing metals often demands more energy use in comparison with producing plastics.
- Lead-free solder applications are in many cases not environmentally beneficial from all environmental perspectives. It leads to avoided potential toxicity because of lead elimination but these effects should be balanced with the additional resource depletion created. Huisman (2003) shows that strategies restricting the use of lead reduce the total life-cycle environmental impact by a factor 2 to 4 (depending on the end-of-life scenario) when resource depletion is not taken into account; when a certain weight is assigned to resource depletion, the most common lead-free soldering alternatives (such as SnAgCu) can score worse from an environmental perspective. Also increased demand for tin could pose a resources problem.
- Eliminating flame retardants in order to reduce potential toxicity will result in use of more primary materials, and consequently in use of more production energy.

The distinction between environmental impact categories, as made above, can help to gain a life cycle perspective, as the various types of impacts are to some (limited) extent related to the various life-cycle stages; resource depletion is a category affected by mining/manufacturing, emissions are related to energy use (and the way electricity is generated) in for example manufacturing and use, and potential toxicity is relevant for the end-of-life stage, a life-cycle stage where also relevant in terms of resource depletion. This is indicated in Figure 1, where the inner ring depicts the environmental impact categories, and the outer ring the life-cycle phases in which they are most relevant.

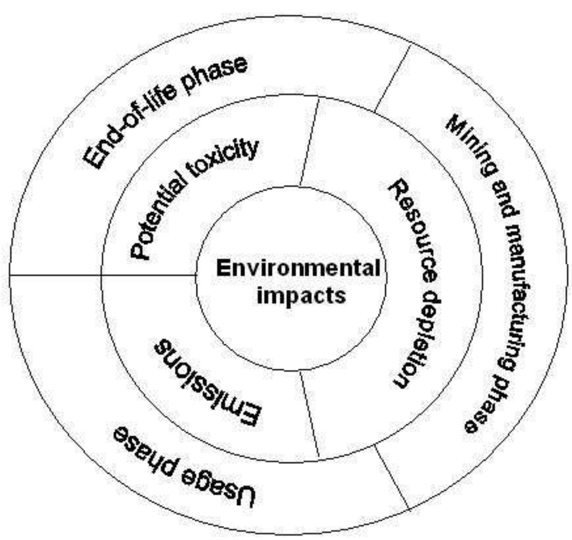

Figure 1: Main environmental impacts over life cycle stages

In the context of design and design rules, a division in life cycle stages has been used substantially more often than the division in environmental impacts. This has often resulted in a one-dimensional view in the sense of concentrating on one simple environmental aspect, in particular in practical applications in industrial contexts. As such there is no objection against this because it provides a focus, which is often needed for practical implementation. Few ecodesigners have time nor budget to take a real holistic perspective. But this one-dimensional focus, be it one particular environmental perspective (emissions, resources, potential toxicity) or life cycle phase, brings about the danger of counterproductive interpretations. The following examples show cases from the electronics industry where results from generally applied design and engineering rules have repercussions in other life cycle phases.

- Liquid Crystal Display screens versus Cathode Ray Tube screens; Due to more energy-efficient technology, LCD screens have a lower environmental impact during the usage phase. In fact, in Japan it was calculated that the change over from CRT to LCD technology contributes to reduction of power consumption to 3 billion kWh, which is equivalent to the amount of total power consumption consumed by about one million households yearly. This was only realised by sacrificing an increase of environmental impact in the manufacturing phase (Socolof et al., 2001). Since 2003, the learning curve in combination with more favorable economies of scale has made that the environmental impact of LCD screens matches or even favors that of CRT screens.
- Use of plastics instead of metals; a lower environmental impact in the production phase is realised at the cost of higher environmental impacts (or less benefits) in the end-of-life phase, for example through the use of larger transformers..
- Miniaturisation of electronics; a higher energy efficiency in the usage phase is realised at the cost of an increase in potential toxicity in the end-of-life phase and an increase of environmental impacts in the production phase.

The examples given in this section show that when the chief thrust of DFE is to be seen as lowering the environmental impact over the product’s whole life-cycle, balancing of overall impacts can mean that either one impact category or one life-cycle has to sacrifice environmental load in order to achieve a big gain elsewhere. Even the use of potentially toxic substances like lead-containing solder, brominated flame retardants and other potentially toxic substances can have a high functionality value and can therefore – when rightly applied – lead to substantial material and energy savings. For this reason attention should not only be paid to input management, but also to output management: bring potentially toxic substances after their (useful) functional life under control in the end-of-life stage, for instance by having in place appropriate recycling (for inorganic substances) or incineration systems (for organic substances). DFE principles like Anastas and Zimmerman’s’ principle 1, which states that "'...all material and energy inputs and outputs should be made as inherently non-hazardous as possible...' can therefore be qualified as lacking a life-cycle perspective. A prerequisite for being able to weigh how such design solutions turn out in the full life-cycle perspective remains to be a proper weighing system; it was already indicated above that considering potential toxicity next to resource depletion and emission, be it as a part of LCA or not, is a necessary condition for this.

4.3 Design for Environment has a much wider focus than just environment.

Design for environment can have substantial benefits outside just the environmental focus. This is illustrated by the following anecdote. At an electronics multinational's plant in Taiwan, in the mid nineties a student was assigned to do his graduation project, concerning an environmental redesign of a computer monitor. The student found out a couple of things; first of all he learned that in the early design of the monitor, a large metal case was designed at the back of the monitor tube, in order to prevent electromagnetic radiation to become a problem. At the time, this was a sensible design solution. Secondly, the student learned that over time, with increasing demands for functionality, this Faraday's cage had become to function as a coat hanger for additional circuitry and components. But over the years, circuitry design had become more sophisticated, and there was no longer a need for this big a Faraday's cage. But as it had shifted primary functions, the cage remained in the design with its original dimensions. Surprisingly, this situation persisted until this student, with a few basic ecodesign rules in his luggage, recognised the problem by looking at it from an environmental perspective. The result was a complete redesign of the monitor, with substantial environmental and economical gains.

By some, 'environment' is still viewed as a standalone issue, as a necessary issue to address, rather than the source of creativity for product improvement that it can be, as shown in the following examples.

Example 1: Upgrading services for TV sets

Below, a summary of a study is presented on the feasibility of upgrading services for TV sets (see also Stevels and Boekee, 2001). This study is representative in its use of a number of practical application principles which emerged from many practical environmental (re)design studies in a cooperation between Delft University of Technology and Philips Consumer Electronics in the 1999-2005 period. These included

- A distinction in five focal areas (energy consumption, material application, packaging and transport, chemical content, and end-of-life), relevant for environmental assessment in the electronics industry. This split-up keeps both problems and solutions manageable.
- Addressing benefits for all stakeholders involved. This means addressing material, immaterial and emotional benefits for company, customer and society. Questions that need to be answered are:
    - What is the business benefit in material (money) and immaterial (image) respect?
    - What is the customer benefit in terms of cost of ownership, convenience and emotion?
    - What is the feasibility in technical, financial (investment) and organisational terms?

These notions have been combined in the Environmental Benchmarking methodology (Boks and Stevels, 2003), which has proved to be instrumental in integrating environment in to regular business at Philips Consumer Electronics, for example through the introduction of Green Flagships, which are now a crucial element in Philips' green marketing and communication strategy.

In the aforementioned study, in order to identify target groups for this commercial afterlife service a customer segmentation analysis was done by taking a 'standard' buyer/user group segmentation (listed horizontally, running from 'high end' to 'low end' product buyers), and correlating this with seven archetypes of environmental behavior (identified in Stevels, 2000). This revealed the picture displayed in Table 3.

Attitude to environmental issues	**Home Aesthetics 13%**	**Enthusiasts 16%**	**Techno-connaisseurs 20%**	**Prudents 20%**	**Uncertain 18%**	**Rationalists 13%**
15% Green engaged (++)		X				X
15% Env.ironmental Optimists (+)				X		X
13% Env.ironmentally Disoriented (+)				X	X	
15% Environent is. too complicated (0)			X		X	
15% Environmental pessimists (0)		X		X		
10% Growth optimists (-)	X		X			
17% 'Enjoy life' (--)	X	X				
Environmental attitude of buyer/user group	--	-	-	+	+	++

Table 3: Correlation between general buyer/user characteristics and environmental attitudes about consumer electronics.

With two exceptions, all crosses in this table are located on the diagonal from bottom left to top right, giving evidence to the conclusion that clearly, various buyer/user groups have distinct environmental characteristics.

In a further step, the relation between these buyer/user groups and their replacement behavior of first users of TV sets was analyzed (Table 4).

Consumer segment	Life time at replacement (years)	Discarding due to low functionality (%)	Discarding due to irrepairability (%)	Viewing time/day (hrs)
Home Aesthetics	9	50	50	3.6
Enthusiasts	8	67	33	2.3
Techno-connaisseurs	9	46	54	2.4
Prudents	11	34	64	4.4
Uncertain	11	31	69	4.6
Rationalists	10	46	54	3.7

Table 4: Replacement behavior of first users of TV sets

This table allows for some remarkable conclusions. In the group with generally negative environmental attitudes (Home Aesthetics, Enthusiasts, Techno-connoisseurs, the HAETs) products are replaced earlier (average 8.7 years) than by the environmentally positives (Prudents, Uncertains, Rationalists, the PURs, average 10.6 years). This correlates with the fact that more TVs are still functioning at the PURs (37%). Surprisingly, the table allows also for the conclusion that user groups with a positive environmental attitude have their TVs switched on for longer hours, namely on average 4.2 hours/day in contrast to 2.7 hours/day for the HAETs. In conclusion, design allowing for postponement of replacement at the first user should primarily cater the HAETs target group. Items like good styling, new technology/features and quality are more important than for instance energy consumption (although from an environmental perspective the opposite is true).

On basis of these characteristics several design strategies (often those recommended in literature to foster durability) to be linked to the commercial afterlife service were evaluated. The results of this assessment are summarised in Table 5. On the left hand side the durability strategies are mentioned.

In these considerations, a central issue has been that the energy consumption in the user phase is much more important in the environmental load over the life cycle than the materialisation of the product itself. The design strategy chosen should fulfill the needs and benefit of the target groups in general but also include the possibility to lower energy consumption in line with latest technology available. This condition makes that all strategies related to styling and function integration are getting low scores, irrespective to whether they fit to the producer interests.

In fact, in this way only two strategies can be selected: functional upgrading and tailor made functionalities. Due to the costs both for the user and the functional upgrading design strategy is preferred under the condition that the user can earn back the additional cost of the upgrade by the lower power consumption in the phase after postponement of replacement.

	Customer need	Customer benefit	Customer cost	Strategic fit in business	Financial benefit for producer	Environmental benefit
Adding functional upgrading	++	++	-	0	+	++
Tailor-made functionality	+	++	--	-	0	+
Styling upgrade	++	+	0	+	+	0
Tailor-made styling	+	+	--	-	0	++
Timeless design	+	0	-	+	0	0
Emotional bonding	+	+	0	+	+	--

Table 5: Evaluation of design strategies to support commercial afterlife service

Example 2: Recycling of cellular phones

A second example illustrates how combining environmental and economical perspectives will lead to different conclusions than separate consideration of these perspectives. It also illustrates how "Products processes, and systems should be "output pulled" rather than "input pushed", as stated in Anastas and Zimmerman's principle 5 (2003).

In the electronics industry, and in particular when end-of-life issues are concerned, this is a very relevant principle. In fact, many examples exist where non-compliance to this principle is the cause of (proposed) eco-inefficient solutions. One such example is the case of cellular phone recycling.

Based on the Dutch Ecoindicator 95 method (Goedkoop, 1995), in an analysis presented in (Boks et al., 2001), a breakdown of the average environmental impact of a range of 20 cellular phones (1998-1999 models) is given (Figure 2). It should be noted that this analysis is about cellular phones without batteries and adapters, as these are usually collected through other channels (adapters) or collected separately (batteries).

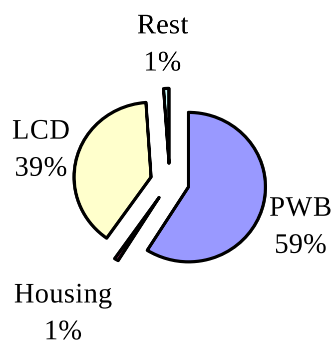

Figure 2: Environmental impact of cellular phone parts

Clearly, the environmental impact of cellular phones during production and recycling, summed together, is mainly caused by two product parts, the Printed Wiring Board (PWB) and the Liquid Crystal Display (LCD) assembly. The remaining impact is caused by the covers, keypad, antenna, speaker and other parts. This means that about 98% of the impact of a cellular phone without battery is caused by two parts that only make up 40-63% of the weight of the phone (avg. 50%).

For the same sample of cellular phones, it was found that the total average end-of-life yield in monetary terms is almost completely made up of gold and palladium revenues. Silver (low concentration and less expensive than gold or palladium) and copper (high concentration since it is also found outside PWB but low price) have both a marginal contribution. The revenues from ferrous metals and aluminum are negligible. Based on these data, it can be concluded that the palladium and gold contents in a phone are the only materials that are significant from an economical point of view. From an environmental point of view, there is the fact that especially precious metals such as silver, gold, platinum and palladium, mainly found in integrated circuits, have very high ecoindicators and therefore considerably contribute to the environmental impact of PWBs. Because on average, 93.5% of the copper in a cellular phone is found on the PWB (the remaining 6.5% is found mainly in the antenna), and gold is only found in the PWBs, it is clear that, based on economical as well as environmental considerations, no parts are of significant importance from both an environmental as well as an economical point of view other than the printed circuit boards.

When looking at factors from an environmental perspective only, the only relevant part is the LCD assembly. An environmental analysis shows that a 10% size reduction of an LCD screen will on average lead to a 4% reduction in environmental impact of the phone during the end-of-life stage. On the other hand, the LCD assembly has negligible impact (positively or negatively) on financial results.

Another factor sometimes thought to be important is the phone housing. Still, from both the ecological and economical analysis it can be learned that the significance of this is very limited. The housing does not contain any material with high environmental impact (unless contaminated with flame retardants), nor does it significantly worsen or contribute to economical results at this time. One aspect in which housing is of any relevance is that it might increase weight-based recyclability once it is assumed to be recyclable. Technology developments aimed at rapid disassembly of phone housings (*e.g.* Chiodo and Boks, 2002) could prove worthwile in the future once a market for secondary plastics is well developed and prices will have increased. But this is certainly not near future.

Currently, EU draft legislation is treating cellular phones like many other consumer electronics products, requiring high weight-based recyclability percentages that can only be achieved by recycling of the plastics present in the phone. Research at Delft University of Technology has analyzed various end-of-life strategies for cellular phone recycling, including disassembly and recycling of plastic housings in order to reach higher weight based recyclability percentages, and separate collection and treatment of cellular phones (Huisman 2006). In the latter option the aim is to collect cellular phones separately with adjusted shredding and separation settings. Results unambiguously show that despite the plastic recycling effort, the increase in environmental gain is negligible. Furthermore the costs for this option are relatively high and lead to a major decrease in revenues.

The second option of separate collection and treatment results however in a higher eco-efficiency. The result is only valid under the assumptions that a sufficient amount of phones is collected. The adjusted shredding and separation settings prevent the loss of precious metals to other fractions than the copper fraction. The shredding and separation settings in this case deliver only two fractions: a relatively small and pure ferro fraction and a copper fraction containing almost all other materials. Compared with the default end-of-life scenario environmental gains are over 20% and revenues increase 17.5%, even when extra costs for storage, logistics and transport are included (Huisman, 2003). Integrated treatment, which means integral incineration of cellular phones by copper smelters, is likely to be even more eco-efficient; this way no copper and precious metals are lost in the shredding and separation process. The smaller LCED screens currently used in cellular phones, which are currently exempted from obligatory disassembly by EU legislation, are of limited concern, whereas the plastic components are of high caloric value and act therefore as cheap energy for the smelting process.

Hence, this is a good example of a situation where the characteristics of these products (output perspective) demand treatment that is different from the regular brown goods streams (input perspective).

5. Conclusions

The examples referred to in this article allow for three conclusions. First, with increasing knowledge of industrial processes in all stages of the life cycle, it has become clear that Design for Environment will not allow for many generic principles. This is true in particular for the electronics industry, with relatively complex end products that affect all life cycle stages. Secondly, this means that traditional perspectives in Design for Environment, which are still prevailing in many research institutes around the world, are likely to be suboptimal from an eco-efficiency perspective, and can be counterproductive even from a purely environmental perspective. This paper has attempted to illustrate, by aforementioned examples, that there is supportive evidence for the hypothesis about the risk of lack of customization of information, as put forward in section 2.

This has a consequence for what DFE practitioners are and can be: they cannot apply design rules from an ecodesign cook book, rather they are design managers, that need to be able to look across disciplinary and life-cycle boundaries (4.2), weighing functionalities and stakeholder interests (4.1 and 4.3).

Future research will have to address the understanding of drivers of individual industries and even companies in relation to possible environmental strategies, to improve understanding which general Design for Environment principles will hold up as 'generic truths', and which ones will not. To some extent, this can be interpreted as a repetition of a plea often heard in the corridors of the DFE community when and where the potential industrial relevance of so-called scientific research in this field is discussed: to engage in closer communications with industry, not with solely prescriptive motives ('no more tool development!' is a common yell in those corridors) but with an open mind for understanding industry's drivers, do's and can't do's. This is expected, by the authors, to lead to the insight that increased levels of customization of knowledge – whilst sticking to a few truly general principles as put forward in this paper – will be crucial for any improvement in implementation of DFE practices. On a last note, consequently, academic scholars will have to explore the boundaries between what can be regarded as academic research and what should be regarded as environmental consultancy.

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