EcoDesign empirically explored

Design for environment in Dutch small and medium-sized enterprises

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Caroline Gertrudis VAN HEMEL

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*"Samenwerking gebaseerd op inzet en enthousiasme
is het fundament van een duurzame toekomst."*

*"Collaboration on the basis of effort and enthusiasm
is the groundwork for a sustainable future."*

This text was printed on a work of art presented at the beginning of 1998 to all those who had worked on the IC EcoDesign project. It perfectly expresses the way in which a large group of enthusiastic people collaborated in order to stimulate the implementation of ecodesign in Dutch small and medium-sized enterprises.

It is a text which also applies with regard to the cooperation I received from a great many people throughout the course of my PhD research. In terms of actual subject matter, I was given a great deal of support by my doctoral thesis supervisors Han Brezet and Jacqueline Cramer. As 'Mr Networking' and 'Mrs Energetic' you combined a spirit of enterprise, practical orientation, writing talents and thoroughness, thus forming the ideal team to help me obtain my doctorate. Many thanks.
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Marc, thanks for being so patient and for taking my mind off things every now and again. The time has now come to empirically explore the *Achterhoek*!

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1. Introduction

This chapter first gives a short description of the growing concern for environmental issues in industry as well as in the academic world, especially with regard to design for environment. It then introduces the objectives, focus and methodology of the research 'EcoDesign Empirically Explored'. A definition of the terminology used in this PhD-thesis and an explanation of its structure conclude Chapter 1.

1.1 Environmental initiatives in industry

1.1.1 Development of environmental awareness

Since the '70s more serious attention has been given to the environmental burden caused by the production and consumption systems developed by our modern society. At the beginning of this period the anxiety was mainly shared by so-called 'environmentalists': members of environmental action groups. These environmentalists were followed suit by governments world-wide after they realized that the world's resources were not endless, nor were they evenly distributed around the world. They started to develop control systems with the aim to decrease the ever-growing environmental burden caused by our production and consumption patterns. Over the years, industry also started to become aware of the environment, even though that awareness was concentrated in companies that were subject to external pressure. Companies in the chemical industry, for instance, because of activities which had a detrimental impact on the environment.

From curing to prevention

Initially, governmental and industrial environmental concern was curative by nature; it focused on the development and application of governmental standards and industrial cleaning technologies in order to monitor, control and reduce the end-of-pipe environmental effects caused by industrial production (at that time regarded as 'inevitable').

Around 1985 governments started to prompt industry to systematically incorporate environmental concerns in their management procedures by means of so-called 'environmental management systems' (EMS). An EMS is a set of managerial procedures for defining how environmental responsibilities are attributed to employees and how the environmental impacts of a company's activities are measured, controlled, reduced and communicated both internally and externally.

The focus subsequently widened and became more prevention-oriented; including not only managerial procedures and cleaning technology, but cleaner technology as well. Cleaner technology is the modification or innovation of production processes in order to prevent at least some of the environmental burden the production of materials and products causes. An important impulse for cleaner technology (also referred to as 'cleaner production') in the Netherlands was the PRISMA project, a stimulation programme for cleaner technology that was started up in 1988. This was a programme which was strongly inspired by similar approaches in the USA (De Hoo, 1991). The aim of cleaner technology programs like PRISMA was to enhance environmental improvements with regard to the inputs and outputs of specific enterprises. Although included in the prevention concept, the PRISMA project devoted little attention to the emergence of 'cleaner products'. The results show that in practice the focus of attention was primarily on environmental improvements of in-house production facilities.

The PROMISE project

This having been recognized, it was decided to set up the PROMISE project, embodying the third widening of focus. This project moved away from prevention by cleaner production towards prevention through the development of cleaner products. PROMISE is a Dutch acronym for 'product development with the environment as innovation strategy' (Brezet et al., 1994). The PROMISE project aimed at enhancing environmental improvements in product designs while still considering all the stages of a product's life cycle. Cleaner technology in practice focuses primarily on the production stage; in the case of cleaner products the focus widens to encompass all stages of the life cycle of a product ('from cradle to cradle'). The objective of the life cycle approach (or 'chain approach') is to

improve the environmental profile of a product, including the products and consumables needed to make the product function properly throughout all the stages of its life cycle: production, distribution, use, recovery and disposal.
The life cycle approach focuses simultaneously on all existing and potential links in the chain of actors jointly responsible for the development, production, distribution, consumption and disposal of a product. In theory, it is an approach that strives to achieve the participation of all up-stream (suppliers, transporters) and down-stream actors (distributors, maintenance and repair services, re-manufacturers, recyclers, disposers) in product and production improvements. If necessary, non-cooperative actors are replaced by actors who do support the aims for sustainable development.

'Pollution prevention pays'

Along with the shift of focus from end-of-pipe measures to the development of cleaner technologies and finally products, the notion grew that preventing the environmental burden could have beneficial commercial side-effects. The motto 'pollution prevention pays', as well as other, more detailed approaches on the same theme (based on practical experiences in industry), were often used in publications on cleaner technology. Environmental impact reduction could lead to commercial benefits like cost reduction, quality improvement and an increase in production, distribution or more efficient storage (f.e. *Proven Profits from Pollution Prevention* by Huisingh et al., 1986). Governmental bodies in various countries funded demonstration programmes (like the PRISMA and PROMISE projects referred to above and the Australian EcoReDesign project reported by Gertsakis, 1997), manuals and conferences in order to increase the environmental awareness and activities. The objective here was to spread the message 'pollution prevention pays' and to help companies overcome the perceived complexity of environmental initiatives. Exemplary in the Netherlands were the initiatives of the Rathenau Institute and the environmental institutes of various universities like the Erasmus Centre for Environmental Studies (ESM) of the Erasmus University Rotterdam and the Interfaculty Department of Environmental Science (IVAM) of the University of Amsterdam. These institutes firmly believed in the concept of pollution prevention and translated it into practical guidance and industrial experimentation. Other institutes, like the Netherlands Agency for Energy and the Environment (NOVEM), the National Environmental Centre (NMC) and the Regional Industrial Environmental Agencies (BMDs) also played an important role, helping to further enhance the diffusion and practical application of the cleaner technology concept.

How to explain the increasing amount of environmental awareness in industry?

There are several factors which contributed towards this increase in environmental awareness in industry over the past few decades. An initial factor was the publication of various well-documented pleas for environmental protection, starting with publications such as *Silent Spring* (Carson, 1962), the report of the Club of Rome called *Limits to Growth* (Meadows et al., 1972) and *Small is Beautiful* (Schumacher, 1977). In a later phase the report *Our Common Future* exerted a great amount of influence. This report was prepared by the World Commission on Environmental Development (Brundtland Commission, 1987) and introduced the concept of 'sustainable development'. Sustainable development was defined in the narrow sense as 'development which meets today's needs without placing the ability of future generations to meet their needs at risk'. In the broad sense, the concept of sustainable development embraces much more than simply the environment and the needs of future generations. It relates to population growth, food supply, the debts of developing nations, limits on natural resources, industrial development, poverty, habitat destruction, loss of biodiversity, and geographical and transgenerational inequality. Environmental quality is an important and widely accepted aspect of sustainable development. Sustainable development is by no means a steady state but rather a changing process; a process in which the choice of raw materials and the quantities required, the choice of investments, and the choices regarding the direction of technological development and institutional change, are brought into line with the needs of both present and future generations (Van Hemel and Brezet, 1997:38). Documents like *Our Common Future* fueled vivid societal debates and had an enormous impact on the environmental awareness of individuals, simply because they had been successful in translating the scientific knowledge about the environmental effects of our patterns of production and consumption into easy-to-understand long-term forecasts.

Another, maybe even more influential factor contributing to the societal environmental awareness was the fact that the detrimental and irreversible environmental damage started to become perceptible. In

the '70s and '80s consumers had been confronted with environmental limitations during several energy crises and with subsequent environmental disasters in Bhopal, Harrisburg, Seveso and Tsjernobyl. The fact that biodiversity had decreased was scientifically proven. In later years, other environmental problems like the enormous mountains of waste and the dying forests, in Germany and the Netherlands for example, were added to the list of events that brought individuals face to face with the effects of their consumerism.
As a result of these environmental disasters and their related publications it soon became accepted world-wide that the industrialized world could not go on mass-producing and consuming without taking into account the negative effects our behaviour was having on both the environment and the well-being of people in less industrialized countries. The message that the world's resources were far from everlasting, that the effects of emissions to air, water and soil resulted in irreversible effects on and within eco-systems, that our needs were being fulfilled at the cost of the well-being of people in less prosperous countries and of our future generations, was presented in figures, facts and forecasts so clearly that the impact on western society was very strong indeed.
As a result, the societal awareness grew and governments started to feel more responsible for enhancing this awareness and setting up activities to reduce the environmental impact of industrial and other activities. A milestone in this respect was the 'Earth Summit' in Rio de Janeiro in 1992 (UNCED, 1992), a conference that brought together governmental and industrial leaders from all over the world. The result was Agenda 21, an action plan on how to enhance environmental awareness and activities world-wide, signed by more than 150 government and state representatives (Van Hemel and Brezet, 1997:38).
In the Netherlands, the growing environmental concern felt by the government was reflected in the subsequent national environmental policy programmes *NMP-1* (VROM, 1988), *NMP-Plus* (VROM, 1989), *NMP-2* (VROM, 1991), *Nota on Product & Environment* (VROM, 1993) and a stream of other publications.

1.1.2 Environmental management as an academic discipline

Looking at the literature on industrial environmental initiatives we see a development similar to the one sketched above. Illustrative are the many books, manuals and case descriptions on various topics in the field of environmental management. From the late '80s onwards, academic business literature began to devote more attention to the integration of environmental initiatives in the business organization. Various new international journals on environmental management were founded, like *Business Strategy and the Environment* (in 1992), *Greener Management International* (in 1993) and *Eco-Management & Auditing* (in 1994). Why did environmental management flourish as an academic discipline at the beginning of the '90s?
According to Cramer (1997) the first reason is that the emphasis in governmental environmental regulation shifted from imposing environmental legislation (resulting in a defensive attitude in the world of business) to the concept of 'product-stewardship'. Businesses themselves now had to carry the responsibility for lowering the environmental impact of their industrial activities.

Secondly, the question how individual companies should develop their environmental policies became more complex. In the '70s, businesses only needed to choose between different cleaning (or end-of-pipe) technologies; later on they were expected to develop a more prevention-oriented environmental policy. This now involves a far wider range of possibilities; in the '90s, industrial companies have to develop an environmental policy that encompasses not only the companies' own industrial activities, but all activities up-stream and down-stream of the product supply chain as well. This means that consideration must be given to the environmental effects of the total product life cycle, including the effects of transport and the production of materials and components, as well as the production, distribution, use, recovery and disposal of the product. The number of actors in those companies involved in environmental decision-making increased strongly, as did the coordination that was needed to control the environmental initiatives taken by the various corporate departments involved in increasing the eco-efficiency of the company as a whole (including the functions of production, R&D, purchasing, sales and marketing). The environmental issue evolved from a 'control' issue into a 'strategic' one through the shift from an end-of-pipe approach towards environmental supply chain management (integral chain management). A coherent strategic vision on the product 'from cradle to grave', as well as additional managerial skills, is required to achieve this (Steger, 1996).

One of the last reasons mentioned by Cramer is the strong increase in number of external actors that influence any company's environmental policy. In the '70s, companies were only required to deal with environmental pressure groups and their own national government. Nowadays, a whole range of external stakeholders are closely watching the corporate environmental attitude and activities, like suppliers, (industrial) customers, banks, insurance companies, consumer organizations, employees, politicians and the media (IVA, 1995). Competitors and international regulating bodies can also be added to this list.
Of course, the establishment in the '70s of various environmental science institutes at universities also enhanced the development of environmental management as an academic discipline. Institutes like the Erasmus Centre for Environmental Studies in Rotterdam and the Interfaculty Department of Environmental Science in Amsterdam employ researchers eager to study the complex matters related to environmental management, inspired by Prof. D. Huisingh, one of the first 'cleaner production researchers' in the USA and now active in Europe since the late '80s. These researchers functioned as key-players in initiating experiments in industry with the aim of elaborating and further enhancing such principles as 'sustainable development' and 'pollution prevention'. Similar institutes emerged in other countries too like Norway (Østfold Research Foundation), Sweden (University of Lund), Austria (University of Graz), Ireland (Cleaner Technology Center) and Portugal (INETI). In turn, this led to new European research networks on cleaner production such as the PREPARE-EUREKA working group and the European Roundtable on Cleaner Production.

In the late '80s, the academic literature focused on how to enhance industrial environmental awareness and activities, mainly in the fields of environmental management systems and cleaning technology. Several conceptual models and typologies were suggested that help to identify the corporate attitude or state of progress with regard to the environmental awareness of and activities in companies (Petulla, 1987; Steger, 1988; Schot et al., 1991; Roome, 1992). Hass (1995) and Mauser (1996) attempted to compare these models and assess their practical value. Both authors concluded that the suggested models had their drawbacks. One of the drawbacks they mention is that most of these models can be called 'conceptual' in the sense that they are not based on empirical comparative field research. It was as late as 1995 before the first systematic, comparative empirical studies on the implementation of environmental management systems (EMS) and cleaning technology were reported (e.g. De Groene, 1995; Groen, 1995; Bouma, 1995).

From the '90s onwards industrial and academic interest grew in industrial environmental activities that had a scope wider than EMS and cleaning technology. The focus in business and academic literature widened to include aspects of cleaner technology and the development of cleaner products as well. This wider focus was partly due to former policy studies on the subject, published in the '80s. Again, the literature was supported by case descriptions; in certain cases findings were derived from systematic comparative empirical research. The scarce empirical research was descriptive, not explanatory.

In addition to the journals mentioned above that focused on EMS, journals were also founded that focused on cleaner technology, like the Journal on Cleaner Technology and the Pollution Prevention Review. Recently, the foundations have been laid for journals focusing on the development of cleaner products, like the Journal of Sustainable Product Design (UK based, started in 1997) and the Journal of Industrial Ecology (USA based, started in 1997).
From 1993 onwards, various traditional engineering conferences also started to include the topic of developing cleaner products, like the International Conference on Engineering Design (ICED) and conferences organized by the Institute of Electrical and Electronics Engineers (IEEE). Conference papers dealt with technology-focused subjects like disassembly and recycling technologies and methods for life cycle assessment. More business-oriented topics, like conceptual models of how to integrate environmental concerns in corporate R&D, and case descriptions of how individual companies achieved this, were addressed as well. Certain conferences were dedicated to the implementation of environmental concerns in industry, like the conferences of the international Greening of Industry Network (GoI).
The papers show that the industrial and academic efforts have so far concentrated mainly on how to incorporate environmental concerns in existing systems of production and consumption. However, a certain school of writers argues that if industry only makes environmental improvements to suit the existing production and consumption patterns, our world will never become sustainable (Ryan, 1992;

Manzini, 1994; Stahel and Giarini, 1991; Bakker, 1995; Meijkamp, 1997). This belief was already stressed as early as in the mid '70s (f.e. Papanek and Hennessey, 1977). These authors argue that to achieve sustainability we should strive to bring about radical changes in our production and consumption systems.

The three-phase development of industrial and academic environmental concern outlined above is meant to give an initial, somewhat simplified picture of how things took place. In practice, the subsequent application of EMS/cleaning technology, cleaner technology and cleaner products should not be seen as initiatives which exclude one another; these technologies can also be implemented jointly. Moreover, the above outline should not create the impression that an individual company's environmental awareness always develops in three stages. It is always possible for environmental awareness to be initially focused on the development of cleaner products, turning to the application of cleaner technology at a later stage. Finally, the relevance of the various environmental approaches depends largely on the type of industry involved. Chemical companies producing base products will focus primarily on improving their production processes through cleaner technology; the ultimate goal of companies producing durable consumer goods will be to achieve cleaner products.

Limitations

Environmental management theory is therefore developing into an academic discipline. However, it is still in its infancy and subject to certain limitations. Gladwin (1993) states that research in the field of environmental management suffers from certain insufficiencies common to new fields of academic interest. Amongst other things he identifies the following limitations common to environmental management theory: the lack of clear definitions; causal relationships between companies and their 'greening' have not yet been studied; research is not based on empirically verifiable hypotheses; research going beyond the borders of a certain branch of industry is scarce; research often has an ideological instead of a theoretical fundament. In other words, there is a need for empirical, comparative, explanatory research on the environmental behaviour in industry.

So far, environmental management literature has mainly focused on a limited set of topics, summarized as the industrial awareness and activities in the fields of implementing EMS and cleaning technologies. Much less emphasis has been given to the question of how industry can be stimulated towards cleaner production, and ultimately towards developing cleaner products (Green et al., 1994). Only a few studies were based on comparative empirical research as to how companies actually developed products with a low environmental impact during all stages of their life cycle (Crul, 1994; Smith et al., 1996; Dewberry, 1996). The scarce empirical research reported on in the year 1997 has a descriptive, sometimes comparative, but never an explanatory character.
There are very few empirical studies known that could provide a theoretical basis for research on cleaner technology and products. For example: the studies reported by Bakker (1995), who interviewed product developers in Dutch design consultancies, Crul (1994), who studied barriers for ecodesign in Dutch companies, Green et al. (1994), who studied green process and product innovation in British companies, and Den Hond (1996), who compared recycling strategies in the European car industry. More recent comparative business studies were performed by Smith et al. (1996) and Dewberry (1996) who studied ecodesign attitudes and practices in British companies and design consultancies.

One of the last limitations of environmental management as an academic discipline today is its focus on the environmental awareness and activities in large companies, notorious for their individual, considerable environmental impact. Small and medium-sized companies (SMEs), which have an individually limited, but collectively high environmental impact, have hardly been studied so far. According to Rowe and Hollingsworth (1996) SMEs comprise over 90% of the businesses established in the UK and while their activities significantly affect the environment they are still notoriously difficult to reach and to influence. The small and medium-sized enterprise sector (defined as companies with up to 500 employees) collectively, is often said to contribute 70% of all pollution (Rowe and Hollingsworth, 1996); although there is little evidence to back up this claim, the total environmental impact of such a large number of businesses must be significant (Groundwork, 1995). The importance of the accumulated environmental impact of small companies, and the problems involved in reaching them, was also detected in the Netherlands (VROM, 1993).

Environmental behaviour of small companies

Rowe and Hollingsworth (1996) mention several reasons why small companies are difficult to reach. First of all, they assume that the existing programmes and training material were oriented towards those large businesses that have a greater organizational capacity to incorporate environmental concerns and are confronted more directly with public concern about their environmental impacts. Hutchinson and Chaston (1994) state that most of the environmental management literature (and the subsequent solutions) assumes uniformity of business structures. This is not a correct approach: small companies are not simply smaller versions of larger companies, but are fundamentally different in their make up (During, 1986; Dilts and Prough, 1989; EIM, 1995; Coehoorn, 1995).
Secondly, Rowe and Hollingsworth assume that SMEs are generally not inclined to seek outside involvement and commitment. The reasons for this, as reported by Curran and Blackburn (1994), are the long working hours of the owner-managers of SMEs, the costs of attending meetings and seeking advice, and the often-prized autonomy and independence of small enterprises. On top of this, governmental and top-down sources tend to be seen as sources of unwelcome constraint (Curran and Blackburn, 1994). The limited amount of attention given to the environmental attitudes and activities of the SME sector implies that little is known about this sector's specific environmental behaviour.

As stated by Hutchinson and Hutchinson (1995):
'The rapid expansion of research on environmental management and sustainable development throughout the 1990s has tended, until recently, to bypass the SME (small and medium-sized enterprises) sector. [...] In the search for mechanisms to encourage firms to minimize their environmental impacts, the requirements of the SME sector have been largely ignored.'

The picture outlined above leads to the conclusion that, up to now, the strong increase in the amount of attention given to environmental initiatives and the resulting stream of publications has led to little systematic comparative empirical research on how businesses deal with the subjects of cleaner technology and cleaner products. This applies in particular with regard to the environmental awareness and activities of small and medium-sized enterprises. As a consequence, we know very little about how companies, especially small and medium-sized companies, respond to the development of cleaner products.

1.1.3 Terminology

In business, as well as in academic literature, there is a certain amount of confusion because of the terminology used when discussing the various topics of industrial environmental concern. In general, the expression 'environmental management' is used to cover all company activities undertaken for the purpose of managing environmental problems. However, because 'environmental management' is part of the expression 'environmental management system', the two phrases are incorrectly seen as identical.
To prevent confusion, this thesis uses the expression ***environmental initiatives*** (instead of 'environmental management') in reference to all the initiatives a company takes to reduce the environmental impact of its activities; the expression therefore encompasses subjects like cleaning technology, cleaner technology, development of cleaner products *as well as* environmental management systems (EMS), the managerial procedures that help a company to organize its environmental initiatives.
The phrase ***environmental management system (EMS)*** is only used in this thesis when referring to environmental managerial procedures for monitoring and controlling corporate environmental impact. Today, EMS can be certified by means of the BS 7750 scheme (British Standards Institute, 1992), or the European EMAS scheme (Environmental Management Auditing Scheme). Companies will soon be allowed to present their EMS for ISO 14001 certification by the International Standardization Organization. In theory, an EMS supports all corporate environmental activities; in practice, however, an EMS usually results in cleaning and cleaner technology, simply aiming to comply with the regulations.
Also, the expression ***environmental management theory*** is used in this thesis as referring to the related academic discipline. As defined by Cramer, environmental management theory is the academic discipline that studies the development of corporate environmental policy (Cramer, 1997). This means that environmental management theory encompasses all topics of corporate environmental concern .

The term ***cleaning technology*** is used to refer to the end-of-pipe measures a company takes to control the environmental effects of its industrial activities. In short, cleaning technology concentrates on monitoring and controlling streams of solid waste and emissions to air, water and soil.
Another often-used expression that causes confusion is 'cleaner production'. Cleaner production usually refers to the development or implementation of cleaner production techniques. However, in several publications the term cleaner production refers to the development of cleaner production techniques, as well as to the development of cleaner products (UNEP, 1996; Van Berkel, 1996). To prevent confusion, this term will be avoided altogether in this thesis. The term ***cleaner technology*** will be used instead, referring to the development and implementation of cleaner production techniques.

Finally, the environmental initiatives of any company can focus on the development of ***cleaner products***. Now there is a certain amount of overlap between the topics of cleaner technology and cleaner products, both devoting attention to cleaner production techniques as well as cleaner product designs. Whereas in cleaner technology the focus is on cleaner production techniques, some design aspects might be addressed as well. While developing cleaner products the focus is on developing cleaner product designs, yet some attention is also given to the production processes involved. In summary, the relation between the various topics in the field of industrial environmental initiatives, as distinguished in this thesis, is illustrated in Figure 1.1.

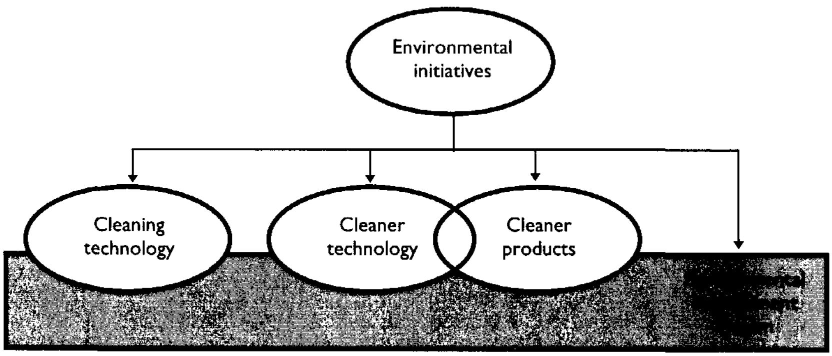


Figure 1.1 *The relation between the topics 'cleaning technology', 'cleaner technology', 'cleaner products' and 'environmental management systems' (EMS), as the subsets of environmental initiatives*

Environmental management system (EMS) is purposely visualized as supporting the other three topics in the field of environmental initiatives. This stresses the fact that it consists of managerial procedures intended to support and coordinate the topics of cleaning technology, cleaner technology and the development of cleaner products.

1.2 Design for environment

1.2.1 Reducing a product's environmental impact in all stages of its life cycle

There are many variances in the terminology used to refer to the development of cleaner products (Bras, 1995; Dewberry, 1996). Often-heard expressions are 'clean product development' (used as a generic term in this chapter so far), 'green design' (used for instance by OTA, 1992), 'green product innovation' (for example used by Green et al., 1994), design for the environment (used mostly in engineering literature, for instance used by Sweatman et al., 1997), life cycle design (often used in US publications, for instance by EPA, 1992), environmental-conscious design and manufacturing (often used in the UK), ecodesign (often used in the Netherlands), ecoredesign (often used in Australia, for instance by Ryan et al., 1992) and sustainable product development (used in the Netherlands, for instance by Van Weenen (1994) and the UK, for instance by McAloone and Evans (1996)). These verbal

shadings tend to cause confusion. One example being that the term 'life cycle design' is commonly used in the US with a similar meaning to the other terms mentioned above. However, in the UK the same term was used when referring to approaches that build heavily on the use of Life Cycle Assessment tools (Dewberry, 1996).
Ultimately, all the above terms refer to a similar approach: revealing the aspiration to reduce a product's environmental impact in all the various stages of its life cycle, including those products and consumables needed to guarantee the product's proper functioning. Still, given that each term reflects a certain approach towards the issue, authors and institutes do select their preferred term with care.

The expression ***design for environment (DFE)*** will be used in this thesis. Design for environment means that 'the environment' helps to define the direction of design decisions. In other words, the environment is a co-pilot in product development. In this process the environment is given the same status as the more traditional product values such as profit, functionality, aesthetics, ergonomics, image and overall quality. DFE considers the environmental aspects in each stage of the product development process, striving to achieve products which have the lowest possible environmental impact throughout their entire life cycle. Ultimately, design for environment should lead to more sustainable production and consumption (Van Hemel and Brezet, 1997). This description corresponds with the definition given by Allenby and Fullerton (1991):"Design for environment designates a practice by which environmental considerations are integrated into product and process engineering design procedures. DFE practices are meant to develop environmentally compatible products and processes while maintaining product price/performance and quality standards".

The expression 'design for environment' is preferred in this thesis since it matches the product development perspective of the Faculty of Industrial Design Engineering at Delft University of Technology, the origins of this thesis. Moreover, it is a term which follows the tradition in publications on engineering design, for example the papers written for the International Conference on Engineering Design. Traditionally, specific foci of attention in the field of engineering design are referred to with the words 'Design for X', resulting in expressions like Design for Manufacturing (DFM), Design for Assembly (DFA), Design for Cost (DFC), Design for Quality (DFQ) and Design for Safety (DFS). According to Dewberry (1996) these terms are now commonplace within the manufacturing industry and have been integrated in design thinking for a number of years. Referring to MacKenzie (1995) Dewberry states (1996:38): "Design for Environment terminology transcends the barriers associated with other eco-product terms due to the already familiar phrase 'design for ...'. This is useful in integrating eco-product philosophies in design development and manufacturing practices and can be seen as series of 'stepping stones' from green design towards achieving a more holistic approach of sustainable design".

Does this mean that we think DFE should be treated as a new 'Design for X' approach? Van Hemel and Keldmann (1996) conclude that the answer should be no. They compared Design for Environment with other Design for X approaches and came to the conclusion that DFE has similarities with other DFX approaches. Like any DFX, DFE is a phrase that covers a number of elements, such as a specific mind-set, procedures and tools. However, contrary to other DFX approaches, DFE has certain characteristics which impede its autonomous diffusion in the practice of product development. Therefore, in terms of its implementation in industry, DFE needs to be given special support.

1.2.2 Evolution or revolution?

Literature on DFE shows that opinions differ as to how to approach this subject. The various approaches taken towards clean product development can be mapped on a scale with two extremes; the first can be called 'evolution', the other 'revolution'.
According to the evolutionary approach, the starting point for the environmental improvement of a product is that product's current life cycle. The objective is to analyze the environmental bottlenecks of a certain product in the various stages of its life cycle by performing, for example, a Life Cycle Assessment (LCA), and then generating, selecting and realizing environmental product improvements. The key words are product modification and pragmatism. This approach is the most common one and is used in most incentive programmes and manuals for cleaner product development, for instance the PROMISE manual (Van Hemel and Brezet, 1997).

However, the revolutionary approach claims that the evolutionary approach can not lead to sustainable patterns of production and consumption: revolutionary thinking is necessary to achieve this. In the revolutionary approach the starting point should not be the actual product but the societal needs that are fulfilled by that product. The questions that precede any product development are: does the product's current function actually meet a basic societal need, or is this need being created 'artificially' and maintained by industry? Can this function be fulfilled by a product or service that has a radically lower environmental impact? As a result, analyzing the environmental impacts of the product is seen as a redundant and even counter-productive activity since it may commit the company to continue with the product's present concept, stopping it from generating totally new function fulfillment. The key words here are innovation and idealism. Leading writers in this field are Papanek (1985, 1995), Stahel and Giarini (1991) and Manzini (1990, 1992, 1994).

While some authors claim that the evolutionary approach paves the way to the revolutionary approach (e.g. Fussler and James, 1996; Van Hemel and Brezet, 1997; Cramer and Stevels, 1997) others reject the evolutionary approach, assuming that it stands in the way of the revolutionary approach (Van Weenen, 1994; Bakker, 1995). This discussion has a strongly normative and intuitive character. To date, little experience has been had with the development of revolutionary environmental product system innovations since these are more complex and involve more risk than environmental product modifications. Future longitudinal research might reveal whether evolutionary environmental product improvements enhance or block the way to revolutionary environmental product system innovations.

The evolutionary perspective is often referred to as design for environment (or ecodesign, life cycle design, green design, environmental product development) and the revolutionary perspective as sustainable product development (SPD). In theory, the scope of SPD reaches further than that of DFE: SPD strives not only to care for the environment, but also to achieve a fairer distribution of prosperity and welfare over the world (Dewberry, 1996). In their practical operationalization however the DFE approach and the SPD approach have much in common.

In 1997 it became fashionable to support the debate on the best approach, the evolutionary or the revolutionary approach, by awarding a factor. The revolutionary approach is generally given the factor 20: it has the potential to reduce the environmental impact by a factor of 20 (if the impact was 100, the remaining impact (100/20) is 5). The evolutionary approach is attributed a factor between 1,5 and 4. Examples of publications that use factors extensively to reflect rates of eco-efficiency are: *Factor Four; Doubling wealth, halving resource use* by Von Weizsäcker et al. (1997) and *Eco-efficiency; Breaking the link between economic growth and environmental damage?* by the OECD Pollution Prevention and Control Group (1997).
The origins of this kind of environmental impact reduction factors are to be found in a clearly set out formula (Weterings and Opschoor, 1992; Jansen and Vergragt, 1993) which specifies the current levels of pollution as the product of the following three terms: Population, Gross Netto Product (GNP) per capita and Pollution per unit of GNP. Over the next 25 years the world's population is expected to at least double; the GNP per capita is expected to increase fourfold. To maintain the current level of pollution over the next 25 years the equation shows that the pollution per unit of GNP should decrease by a factor of 8. If we want to decrease the level of pollution to 40% of the current level, it is necessary to decrease pollution per unit of GNP by a factor of 20.

Level of pollution	=	*Population*	*x*	*GNP per capita*	*x*	*Pollution per unit of GNP*
1	=	*2*	*x*	*4*	*x*	*1/8*
0,4	=	*2*	*x*	*4*	*x*	*1/20*

While this formula is a very simplified one, it still shows that the growth in population, the increase in consumption and the level of pollution are very much interdependent. The factors risk being misused in the environmental debate, being used to support ill-defined and hardly verifiable statements. Nevertheless, regardless of their poor operationalization, these factors are worthwhile since they communicate the environmental ambitions of the persons who use them.

Exemplary of this is a conceptual model developed by Brezet and Stevels (Brezet, 1997) that visualizes their view on the desired process of moving from evolutionary product improvements to revolutionary product system innovations. Brezet and Stevels distinguish four types of ecodesign innovation. Product improvements and the redesign of products (types 1 and 2) can achieve eco-efficiency improvements of up to 80% (factor 5). According to Brezet and Stevels, in order to really make the breakthrough towards sustainability, eco-innovations should include product function innovations and product system innovations (types 3 and 4). The aim then is to achieve a factor 20 improvement rate, implying a 95% reduction in environmental impact.

1.2.3 The roots of design for environment

The development of cleaner products is a subject which, since the early '90s, has attracted more and more attention throughout the entire world. However, this subject is not a new one for product developers. As far back as 1960 Vance Packard published his book *The Waste Makers* in which he criticized the role of industry, product developers and advertisers for their influence on consumption; in 1985 Victor Papanek published *Design for the Real World*, in which he put forward the argument for sustainable product development (although the term 'sustainable development' only started to be used widely in 1986 after the publication of *Our Common Future* (Brundtland, 1987)). A detailed overview of these developments, called 'An historical overview of ecodesign', is given in Dewberry's thesis (1996, pp. 14-27).

While some product developers have been aware of the subject of developing cleaner products since the '60s, it has only been applied systematically in recent years. In the Netherlands this subject has only attracted structural attention since the early '90s. A milestone in this respect was the previously-mentioned PROMISE demonstration project. PROMISE is a Dutch acronym for 'product development with the environment as innovation strategy' (Brezet et al., 1994). The objective of this project was to stimulate the awareness and application of cleaner product development in Dutch companies (in the programme this is referred to as *Ecodesign*). The fundament of this programme was the EcoDesign project (1990 - 1993) coordinated by TNO Industry and Delft University of Technology (Van der Horst and Te Riele, 1994). The objective of the EcoDesign project was to perform ecodesign pilot projects in eight medium-sized to large companies in close cooperation with those persons responsible for product development. An experienced ecodesign team, consisting of an environmental specialist and a product developer, worked together with each company for a period of 6 to 12 months. The EcoDesign project resulted in a set of eight interesting ecodesign cases, experience with using ecodesign tools (like the so-called 'MET-matrix' and 'Life Cycle Assessment'), and experience in consulting with companies on using ecodesign in product development. This experience was used to optimize the methodology applied during the ecodesign intervention, consisting of a step-by-step approach, structured according to the traditional product development process. One of the main conclusions was that the best approach for creating ecodesign awareness and initiatives in a company is to establish a link with the company's specific type of products and development process. A good way to guarantee this strong relation was to select one of the company's products and assist the company in applying the step-by-step approach to this specific product.

The Dutch PROMISE manual on ecodesign (Brezet et al., 1994) was based on the experience gained from the eight ecodesign projects. The objective of this manual is to help companies set up their own ecodesign projects. The basis for the manual was a combination of ecodesign methodology and a description of the ecodesign cases. Furthermore, the PROMISE project was also inspirational in developing the *Nota on Product & Environment* (VROM, 1993), a policy document in which the responsible Dutch Ministries presented their proposal for further enhancing the development, production and consumption of cleaner products in the Netherlands.

1.2.4 Lessons learnt in the past

What did the PROMISE project teach us about the integration of environmental issues in product development? An important conclusion was that the integration of environmental concerns does not bring about any fundamental change in the structure of the product development process.
The basic structure of the product innovation process (as described by f.e. Andreassen and Hein (1986), Roozenburg and Eekels (1995), and Pahl and Beitz (1996)) does not change when environmental issues are integrated in product development. However, some quite clear differences are seen regarding the practical detailing of this structure when 'environmental' product development is compared with

'traditional' product development. The PROMISE project taught us that if we wish to develop cleaner products we must at least internalize a new mind-set (the life cycle approach) and consider new and specific activities (like setting environmental targets for product development or environmental benchmarking), new types of information (e.g. information required to be able to identify every environmental impact during a product's life cycle), new methods (like Life Cycle Assessment) and new forms of cooperation (cooperation within the product supply chain or branch of industry).

Although the PROMISE manual helped larger companies to start up their individual ecodesign initiatives, the approach soon turned out to be less suitable for small and medium sized enterprises (SMEs) (in this thesis SMEs are taken to be companies with a maximum of 200 employees). As mentioned in the preceding section, small companies are notoriously difficult to reach and influence (Rowe and Hollingsworth, 1996). Their form of organization tends to limit them in terms of incorporating environmental concerns. Furthermore, SMEs are generally disinclined to seek outside involvement and commitment because of their limited capacity in terms of time and resources. Moreover, they are confronted less directly with public concern about their environmental impacts. The problem of how to reach and influence small companies not only exists with regard to the incorporation of environmental concerns in their business. This difficulty is also often addressed in innovation management literature focusing on the innovational behaviour of small companies (During, 1986; Dilts and Prough, 1989; EIM, 1995; Coehoorn, 1995).

A certain kind of support is required to encourage SMEs to develop cleaner products. This led, in 1994, to the Dutch government deciding to initiate a new ecodesign project, this time focusing on a large group of small and medium-sized companies. The Innovation Centre Network in the Netherlands (ICNN) was given the responsibility of developing, coordinating and executing this comprehensive ecodesign stimulation project (which started in 1995 and runs until December 1998). This new project, called the ***IC EcoDesign project***, offered a great opportunity to gain more insight into how SMEs respond to the development of cleaner products.

1.3 The IC EcoDesign project

1.3.1 Introduction

What are the objectives, organization and content of the IC EcoDesign project? In short, this is a project that aims to create awareness for ecodesign ('design for environment') among a large group of small and medium-sized Dutch enterprises and to stimulate them to actually apply the principles of ecodesign to one or more of their products.

The Innovation Centre Network

The organization selected to implement the project was the network of non-profit Innovation Centres (ICs), the Innovation Centre Network in the Netherlands (ICNN). This network was established in 1989-1990 with funding from the Ministry of Economic Affairs (Coehoorn, 1995). Every regional IC has a director and, depending on the region, employs four to ten consultants. The aim of these ICs is to improve access to newly developed technological knowledge for small companies, enabling them to innovate faster. They are similar to the regional technology advisory centres that exist in other European countries. The network comprises 140 consultants who advise 20,000 small companies annually.
One of the reasons why the ICNN was chosen to both develop and execute the ecodesign project was because this organization is familiar with many of the product-related issues facing small companies; one-third of the questions put to ICs relate to new product development (Coehoorn, 1995). Apart from this, the ICs had already built up environmental competence thanks to their involvement in an earlier 'Cleaner Production' project involving audits of 600 companies to improve the environmental aspects of their production processes.

In order to create a strong support infrastructure (given the fact that ecodesign was a new topic) 23 IC consultants and IC project assistants were given general training in ecodesign and specific training in ecodesign audits.

The consultants started auditing the first group of companies in February 1995. Since then, all consultants and project assistants have come together every three months to exchange knowledge and experiences, and to receive training on various ecodesign topics. These consultants were frequently asked questions about environmental issues which they were unable to answer immediately. Should this happen, they were able to request support from a so-called 'ecodesign helpdesk'.

The aim of the IC EcoDesign project

The uncertainty surrounding the benefits and improvements resulting from ecodesign was assumed to be a major obstacle standing in the way of green product development, especially among smaller companies (Crul, 1994; Van Hemel and Keldmann, 1996; Hanssen, 1997). Most companies have questions that are not easy to answer: Is ecodesign relevant to our business? How can ecodesign be applied to our products? What will be the effects of product changes on the environment, on our organization, on our market position, in financial terms, and on the motivation of our employees? In what direction will international legislation and consumer demands develop? How can we set clear targets for ecodesign and achieve them if we are unaware of the consequences?
The aim of the IC EcoDesign project was to make small companies conscious of the opportunities arising from ecodesign, and guide them through the process of integrating environmental demands into their product development processes. One of the key needs was to motivate action by 'learning by doing'. To achieve this, companies were advised on environmental innovation for one of their products. The aim of this approach was to develop competence and competition in ecodesign which other companies could then copy.

The target group

The target group for the IC EcoDesign project was estimated at some 4,500 companies. The most important criteria for selection were as follows:
- that the companies are SMEs (with a maximum of 200 employees);
- that they themselves are responsible for their product specifications (sometimes in association with their customers, usually autonomously);
- that their products are developed in the Netherlands;
- that their products are physical, tangible products.

The aim was to enable 20% of these 4,500 SMEs (a total of 900 small businesses) to participate in the project between February 1995 and December 1998. The assumption was that the effects of the project would cascade to a further 60% of the total target group. There was no restriction on involvement by industrial sector. However, it was expected that six key branches of industry would be represented: metal products, machinery, wood and furniture, electronics, vehicles and rubber/synthetics. For 1995 the target was set at 100 small companies; 95 companies were participating by the end of 1995.
It proved to be not easy for the IC consultants to meet this target. As a result, a few companies participated in the project that did not fully meet the above four criteria.

1.3.2 The IC EcoDesign project approach

The IC EcoDesign project was a follow-up to the ecodesign demonstration programme PROMISE, a programme which had been implemented in medium-sized and large companies. A new method was called for which had to be geared towards the needs of SMEs as well as the working methods of the IC consultants.

SMEs usually have too little time and money to perform activities additional to their day-to-day work. Because of this, the environmental activities undertaken by SMEs tended to focus on good house keeping and cleaner technologies, consequently they had little experience of ecodesign. An auditing method for SMEs was therefore developed, assuming a low level of awareness of ecodesign and a lack of time and money in small companies. Because of the limited initial awareness and lack of capacity it was decided not to start with performing extensive and quantitative life cycle assessments (LCA). Instead, a more qualitative approach was preferred - although it was still based on the total product system and all stages in a product's life cycle. The resulting auditing method was called the ***Environmental Innovation Scan.***

Other specific features of the IC EcoDesign project are the three-phase approach and the short intervention period. A great deal is done to raise the amount of initial interest among management for ecodesign, and to convince them of the merits of participation before the first phase actually starts. Inspiring project documentation, introductory interviews with entrepreneurs and public ecodesign meetings supported this personal approach. Once agreement has been reached on participation in the project, the three-phase intervention can start.

In the first phase, the intention is to increase the awareness of ecodesign by helping the relevant persons in the company to understand the environmental impact of the company's business and its products, as well as the possibility of turning environmental threats into opportunities. This is achieved through the Environmental Innovation Scan, the auditing method derived from the Dutch PROMISE Manual for ecodesign (Brezet et al., 1994). These audits were relatively short, concentrating on the strategic elements of ecodesign decision-making and focusing on one of the company's products. The Environmental Innovation Scan assists the IC consultant and the company representative to answer the following three key questions:

- What must the company do? (mapping the external factors that lead to ecodesign, like legislation, higher waste costs, higher consumer demands, new technologies etc.);
- What does the company want to do? (mapping the internal motivation for ecodesign, like improving product quality, corporate image, cost reduction);
- What can the company do? (mapping the environmental profile of the selected product, following all stages of the product's life cycle).

The outcome of this first phase was an ***EcoDesign action plan*** listing a set of DFE improvement options and actions to improve the environmental aspects of the product in question. ***DFE improvement options*** relate *directly* to the product's design. ***DFE actions*** relate *indirectly* to the product's design, and generally involve research or managerial actions that count for the company's total product range. Within the context of the IC EcoDesign project Van Hemel developed a typology of eight 'ecodesign strategies', visualized in the so-called ***DFE strategy wheel*** (Van Hemel, 1994). This typology presents an overview of actions that can be taken to improve the environmental impact of a product throughout its total life cycle. All ecodesign improvement options are covered by 33 so-called ***DFE principles***, clustered into 8 ***DFE strategies***. For example, DFE strategy 1 is typified as 'Selection of low-impact materials' and clusters the four DFE principles 'Clean materials', 'Renewable materials', 'Low energy content materials' and 'Recycled materials'. The typology of ecodesign strategies applied in the IC EcoDesign project was derived from the DFE strategy wheel. In the ecodesign action plan the improvement options were structured according to this typology.

The second phase starts after the company's Environmental Innovation Scan. In this phase, the company could apply for a partly government-funded feasibility study on certain aspects of ecodesign. The aim of this phase is to investigate the technical, financial or environmental feasibility of one or more of the options suggested in the action plan. The feasibility study itself was generally conducted by a consultancy or by the company itself, sometimes with the assistance of a graduate student.

The improvement options are implemented in the third phase. The company itself, assisted by an IC consultant, is (financially) responsible for this. In 1996 the Dutch Ministry of Economic Affairs introduced an ecodesign credit system which made it possible to obtain partial financing for high-risk investments in ecodesign. This scheme offered the companies additional financial support.

1.3.3 Monitoring the results of the IC EcoDesign project

In 1996 the Dutch Government requested the author of this thesis to evaluate the results of the first year of the IC EcoDesign project. That evaluation subsequently formed the basis for the study reported on in this thesis. A monitoring instrument was developed in the initial stages of the study aiming to measure how the SMEs were performing in terms of design for environment. Since the method used in the IC EcoDesign project failed to supply quantitative life cycle assessments of all the products involved, a new instrument had to be developed to measure the environmental product improvements and organizational learning in terms of design for environment.

This monitor research was carried out in the period between October and December 1996 (about 12 to 20 months after the SMEs had joined the IC EcoDesign project). Thanks to this time span it was possible to assess whether a company had reached phase three of the project (or, alternatively, had stopped at phase two or only phase one). Moreover, it also allowed a measurement to be taken of the extent to which the companies had implemented the ecodesign improvement options as suggested in the ecodesign action plan. The request to monitor the 1995 IC Ecodesign project results offered the opportunity to gather additional data. These data were used to build up empirical evidence for answering the research questions raised at the start of the PhD study with the aim to learn more about the DFE behaviour of SMEs.

1.4 Focus of the study

The objective of this PhD-study is to analyze how small or medium-sized enterprises cope with design for environment in their product development. For this, the two central research questions are:
A. *Why are certain strategies in the field of design for environment more successful than others?*
B. *Why do some SMEs perform well in design for environment while others lag behind?*
If we find the answers to these questions we thus gain insights that could help us remove certain barriers and encourage SMEs to develop cleaner products.

In order to assess and explain the success of the various DFE strategies (research focus A), the following questions need answering:
A.1 *How should the success of the various DFE strategies be measured?*
A.2 *What is the variance in the success rate of the various DFE strategies?*
A.3 *How can the assumed variance in the success rate of the DFE strategies be explained?*

In order to investigate the DFE performance of the SMEs that participate in the IC EcoDesign project (research focus B), the following questions must be addressed:
B.1 *How should the DFE performance of a participating company be measured?*
B.2 *What are the differences in DFE performance of the participating companies?*
B.3 *How can the differences in DFE performance of the participating companies be explained?*

Relevance of the research

The relevance of this research can be broken down into two components: the scientific and the societal component. From a scientific point of view this is the first study that explores, empirically and in detail, the application of design for environment among small companies. Two new measuring methods were also developed: a method for identifying the DFE focus prioritized by the companies participating in the IC EcoDesign project, and a method for measuring a business' DFE performance consequential to the IC EcoDesign project.
Moreover, this study explores those elements that motivate (or demotivate) companies to use design for environment. Whereas this is by no means the first study into this subject matter, the fact that the DFE performance of seventy companies, all participating in the same DFE stimulation project, has been measured, compared and (partly) explained, gives us the opportunity to test certain hypotheses through empirical, quantitative and comparative research. This study is the first attempt to explain how and why (small) companies differ in terms of DFE performance. The combination of design for environment and small companies has not been explored empirically before.
Finally, the investigation of stimuli and barriers for design for environment (stressing the synergy and conflicts between environmental and traditional product requirements) has resulted in new insight.

The societal relevance of the study is as follows. This study resulted from a request made by the Dutch Government to monitor the environmental results of the IC EcoDesign project. That request involved developing an instrument to monitor the environmental results of the IC EcoDesign project and to evaluate the 1995 project results. In other words: the research project had a direct relevance to policy since the research findings are used to assess the outcomes of the IC EcoDesign project and to improve ecodesign consulting procedures. The monitor instrument developed in 1996 will continue to be used in the future; it will be used to evaluate the results of the IC EcoDesign project on an annual basis. Furthermore, this study teaches us more about how small companies cope with the aspect of design for environment in their daily practice of product development. Armed with this knowledge, we can then

attempt to remove the barriers standing in the way of DFE and benefit from the DFE stimuli and thus enhance the application of DFE in industrial practice. The new insights could help to raise awareness of DFE and motivate companies that have not applied DFE to date to take action in this direction. It can also help intensify the DFE initiatives of those companies that were already familiar with the subject. If we achieve this, then design for environment could bring us one step closer to a sustainable society.
Because this study provides insight into the environmental behaviour of SMEs, the outcomes are also of interest to the Innovation Centre Network, industrial organizations and design consultancies involved in giving support to SMEs in the field of DFE.
Finally, this thesis illustrates some of the deficiencies in current environmental management theory. Given that it reveals some interesting future research objectives, universities and other knowledge institutes might be able to benefit from this study too.

1.5 Research methodology

Theoretical perspective

A PhD-thesis about design for environment could be based on two different theoretical perspectives: theory on industrial environmental management (1), or theory on product innovation management (2). Since the 90's, the discipline of environmental management has started to incorporate the subject of integrating environmental issues in product development. However, even though the subject of cleaner product development had been discussed as far back as the '60s, literature on product innovation gives very little attention to this subject. Therefore, the point of departure taken for this thesis was to establish a link with environmental management theory rather than innovation management theory.

Type of research

The study reported in this thesis is typical of comparative, empirical, quantitative field research. It compares and attempts to explain the DFE performance of the companies participating in the IC EcoDesign project. It also sets out to compare and explain the success of various DFE strategies. We can therefore conclude that the research is of a comparative nature. It is empirical in the sense that it makes use of empirical data to assess whether a set of six hypotheses is supported or not. This data stems from the SMEs that participated in the IC EcoDesign project in 1995 (the 'field').
The study is quantitative rather than qualitative, since it sets out to achieve a quantitative measurement of different variables and to explore the relations between these variables by means of statistical analyses. The field of study covered 77 SMEs. Because of this limited number of objects of study only relatively simple, bivariate statistical analyses were justified, like correlation and cluster analyses.

Although the title of this study is 'EcoDesign Empirically Explored', it is actually a mixture of descriptive, explorative and testing research. The fundament of the study is the description of the DFE strategies and DFE performance of those SMEs participating in the IC EcoDesign project. Also, a set of hypotheses has been generated on the basis of literature on environmental management in general and DFE in particular. These hypotheses will be tested by the empirical data generated in this PhD-study.

Data generation

The empirical data needed to judge whether the hypotheses are supported by empirical evidence were gathered by means of two methods: a questionnaire (by mail) and an interview (by telephone). Permission was first needed from the IC consultants responsible for the individual companies taking part in the IC EcoDesign project before the companies could be asked to participate in the research. The 77 SMEs that could be approached were contacted by telephone and requested to complete a questionnaire. At the same time an appointment was made for an interview by telephone. The checklist used for the telephone interview is included in Appendix A; the postal questionnaire in Appendix B.

Number of companies studied

The 94 SMEs participating in the IC EcoDesign project in 1995 provided the empirical material for this study. Of these 94 companies a total of 77 agreed to participate in this research. There were two reasons for non-participation. The first was that the IC consultant concerned had refused permission to approach the company (14 of the 17 non-participating companies). The most common reason for some IC consultants to refuse participation was to safeguard the confidentiality of the (ecodesign) activities undertaken in the individual companies. The second reason was that the company itself refused to cooperate (3 of the 17 companies) even though the IC consultant had assumed that there would be no objection and had therefore given permission for the company to be contacted. This was inevitably because the respondent in question could not spare the time. It was clear that the IC EcoDesign project had had little effect in these three companies: their ecodesign action plans contained very few options for DFE improvement.

Of the 77 companies that did participate in the research, a total of 75 completed the questionnaire; 74 were interviewed by telephone. In practice, this implied that 72 of the 77 companies studied consented to complete the questionnaire as well as to be interviewed by telephone. We may conclude that this was a high response rate. Yet this is not all that remarkable since the companies' respondents were already familiar with and actively involved in the IC EcoDesign project. They knew what the research was about, and were willing to cooperate to improve the project approach and to raise the level of implementation of design for environment in industry.

While a total of 77 companies might seem a large sample, for the statistical analyses required for this study it was still a somewhat limited number. The study needed adjusting to a certain extent in order to bring it into line with the settings and planning of the IC EcoDesign project. Bringing the number of companies up to about 300 would have been scientifically more correct. However, since this was not feasible, we had to cope with the limitations of a modest sample of companies.

Questionnaire and interview

The questionnaire (included in Appendix B in the original Dutch version) requested the company to provide information on the company as a whole, the product involved in the Environmental Innovation Scan, the respondent himself, etc. It was also used to identify the organizational learning regarding DFE as a result of the IC EcoDesign project. It took the respondents about forty-five minutes to an hour to complete and was returned by 75 companies.

The aim of the telephone interview was to reach a detailed assessment as to the extent of realization there was in terms of the DFE improvement options as had been suggested to the company in the DFE action plan. The DFE action plan was the result of the Environmental Innovation Scan, the first phase of the IC EcoDesign project.

The factors behind a company's decision to either realize or reject a certain DFE improvement option were also assessed. These interviews were all conducted on the basis of a pre-structured list of questions relating to each individual DFE improvement option. This list of questions, plus the relevant codes (in Dutch), are attached as Appendix A. This resulted in the assessment of about 600 DFE improvement options of a total of 74 companies. The interviews lasted from 15 minutes to an hour, depending on the number of DFE improvement options listed in a company's DFE action plan.

Respondents

The respondent completing the questionnaire was in all cases the same person interviewed. In most cases he was the company's owner-manager; in several of the somewhat larger companies the respondent was the head of the design department. In most cases, the respondent was the same person that had been involved in the Environmental Innovation Scan that had taken place about one year before the monitor research. In two cases the person involved in the IC EcoDesign project had left the company's employ; the respondent involved in this study was consequently the person who had taken over his job.

1.6 Structure of the thesis

As stated in Sections 1.1 and 1.4 the study reported in this thesis concentrates on two research foci: 'How can we measure, compare and explain the success rate of various DFE principles' (research focus A) and 'How can we measure, compare and explain the DFE performance of individual companies' (research focus B). Both research foci are addressed from a theoretical as well as an empirical perspective.

A theoretical fundament was needed before any measuring could be done. The research questions also had to be elaborated further on the basis of existing theory. Additionally, various measuring instruments had first to be developed. These theoretical issues are dealt with in the Chapters 2, 3 and 4. First of all, Chapter 2 introduces a typology of so called DFE strategies and DFE principles, subsequently worked out in the DFE strategy wheel. This typology is the fundament for the method used to identify the DFE strategies prioritized by the companies that participated in the IC EcoDesign project.
Chapter 3 goes on to explain how the performance of these companies is measured in terms of DFE. The literature used was on measuring the environmental performance in industrial companies in general, and performance in design for environment in particular.
With these measuring instruments in mind it was possible to further articulate the research questions introduced in Section 1.4. Factors that might explain the difference in success of various DFE principles, and factors that might explain the difference in DFE performance between companies, were derived from existing environmental management theory. Chapter 4 presents the outcomes of this theoretical analysis, focusing on factors (in large as well as in small companies) which influence industrial environmental initiatives in general and the implementation of design for environment in particular. By means of the theoretical analyses in Chapters 2, 3 and 4, the research foci A and B introduced in Chapter 1 are elaborated into a conceptual research model with six hypotheses, presented towards the end of Chapter 4.

Having completed the theoretical fundament, it then became possible to generate and analyze the empirical data by using statistical techniques. The empirical findings are subsequently set out in Chapters 5, 6 and 7. Chapter 5 presents the outcomes of the IC EcoDesign project in 1995, revealing on the one hand the success of the DFE principles distinguished, and the DFE performance of the SMEs on the other. Chapter 5 concludes by reflecting upon hypothesis 2, related to research focus B.
Chapter 6 focuses on the DFE principles prioritized by the SMEs, describing the mutual differences in their rates of success. Chapter 6 also sets out to explain why certain DFE principles are more successful than others, reflecting upon hypothesis 1 of this research, related to research focus A.
Chapter 7 then concentrates on the DFE performance of the SMEs in question, aiming to explain the variances in the companies' DFE performance as a result of the IC EcoDesign project. Chapter 7 empirically tests the hypotheses 3 to 6, as distinguished in research focus B.

Chapter 8 concludes the thesis. It presents and discusses the conclusions derived from the preceding chapters. Finally, Chapter 8 presents a set of suggestions for further research related to the subject and gives recommendations for enhancing the implementation of design for environment in industry.
The structure of the thesis as described above is visualized in Figure 1.2 below.

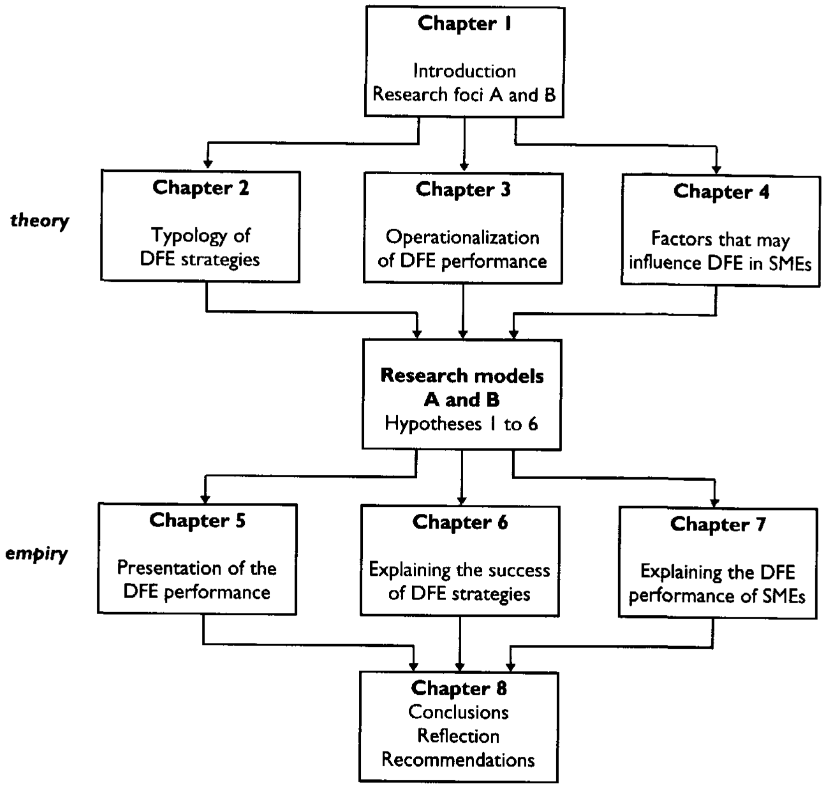


Figure 1.2 *The structure of the thesis*

2. The design for environment strategy wheel

Chapter 2 introduces the typology of so called DFE strategies and DFE principles. This is subsequently worked out in the DFE strategy wheel. The DFE strategy typology is the fundament for the method used to identify the DFE strategies prioritized by the SMEs that participated in the IC EcoDesign project.

2.1 Towards a typology of strategies for design for environment

Many different types of environmental product improvements are possible within the framework of design for environment. A typology of DFE strategies and DFE principles was developed at the start of this PhD-study on the basis of classifications of DFE strategies found in literature (Van Hemel, 1994). The purpose of this was to cluster and categorize these potential 'improvement options', all of which are encompassed in the term design for environment (DFE).
In this thesis, ***DFE strategies*** are defined as potential routes a company can follow if it wishes to apply the principles of design for environment to one or more of its products. The term 'DFE strategies' was chosen in line with the first comprehensive manual on DFE published by the US Environmental Protection Agency, the organization that introduced the expression 'life cycle design strategy' (EPA, 1992). A DFE strategy encompasses a set of two to five so called DFE principles. A ***DFE principle*** is described as a potential means of operationalizing or realizing a DFE strategy.

2.1.1 Existing typologies of DFE strategies

The literature available on design for environment reveals several classifications of DFE strategies. Examples are the *Life Cycle Design Guidance Manual* (EPA, 1992), *Green Products by Design* (OTA, 1992) and the *PROMISE* manual for DFE (Brezet et al., 1994) as well as various publications written by Manzini (1992), Ryan (1993), Smals (1993) and Zweers and van der Horst (1993). More recently, comparable classifications have been developed by Fussler and James (1996), Cramer (1997) and Hanssen (1997). This list of publications, all of which list sets of DFE strategies, is not complete; almost each publication on DFE presents its own specific division of DFE strategies. The above publications refer to DFE strategies as 'goals', 'solution directions' or 'approaches'; the number of strategies mentioned ranges from four to eight. In essence, these listings of DFE strategies have much in common, even though each author selects that specific set of strategies which best suits his personal or professional perspective on the subject of DFE.

An overview of some of the sets of DFE strategies found in literature is given in Figure 2.1 below. The classifications found in literature are listed conform a typology of DFE strategies developed by Van Hemel (1994). This typology of DFE strategy is presented in the first column of the table. It has been re-developed in an effort to achieve the most exhaustive and unambiguous overview of the potential DFE principles. This was done by integrating, completing and re-categorizing the typologies found in literature. Figure 2.1 distinguishes DFE strategies and DFE principles. For example, *Selection of low-impact materials* (DFE strategy 1) is regarded as a DFE strategy; *Clean materials* (DFE principle 1.1) is called a DFE principle. Each DFE strategy encompasses a set of two to five DFE principles.

DFE strategies and principles Van Hemel, 1994	EPA 1992	OTA 1992	Brezet 1994	Smals 1993	Zweers 1993	Ryan 1993	Manzini 1992
1 Selection of low-impact materials	●		●				
1.1 Clean materials	○	●	●	○	○		
1.2 Renewable materials	○		●	●			
1.3 Low energy content materials	○		●	●	○		
1.4 Recycled materials	○		●	○	●		
2 Reduction of materials usage	●		●	●	●		
2.1 Reduction in weight	○	●	○	○	○		
2.2 Reduction in volume	○		○	●	○		
3 Optimization of production techniques	●		●				
3.1 Clean production techniques	●		●	○	○		
3.2 Fewer production steps	○		○				
3.3 Low/clean energy consumption	○		●	●	○		
3.4 Less production waste	●		●				
3.5 Few/clean production consumables	○		○		○		
4 Optimization of distribution system	●		●				
4.1 Less/clean/reusable packaging	○		●	○	○		
4.2 Energy-efficient transport mode	○		●	●	○		
4.3 Energy-efficient logistics	○		●	●	○		
5 Reduction of impact during use						●	
5.1 Low energy consumption		●	●	●	○	○	
5.2 Clean energy source				○	○	○	
5.3 Few consumables needed						○	
5.4 Clean consumables				○	○	○	
5.5 No waste of energy/consumables						○	
6 Optimization of initial lifetime		●	●		●	●	●
6.1 High reliability and durability	●	○	●		●	○	○
6.2 Easy maintenance and repair	●	○	○		○	○	○
6.3 Modular/adaptable product structure	●	○	○		○	○	○
6.4 Classic design		○	○		○	○	●
6.5 Strong product-user relation		○	○		○	○	●
7 Optimization of end-of-life system							
7.1 Reuse of product	●		●	○	●		
7.2 Remanufacturing/ refurbishing	●	●	●	○	●		
7.3 Recycling of materials	●	●	●[1]	○	●	●	●
7.4 Safe incineration (energy recovery)		●					
7.5 Safe disposal of product remains		●					
@ New concept development			●		●	●	
@.1 Dematerialization			○		○	○	●[3]
@.2 Shared product use			○		○	○	○
@.3 Integration of functions			○		○	○	
@.4 Functional optimization			○		○	○	
DFE actions (not ppp-related) [2]							
Improved management practices	●						
Development of take-back system			●				
Industrial ecology							

1) Broken down into material coding, recyclable materials, additives, surface treatment, printing
2) DFE actions are managerial, non-technical issues (not directly product /packaging/production related)
3) Described as 'products become services'

Figure 2.1 *An overview of the various sets of DFE strategies and DFE principles as mentioned in literature on design for environment (● = mentioned as such; ○ = implicitly meant)*

This overview illustrates that the different sources each provide the reader with a specific set of DFE strategies which should lead to products with a better environmental profile. In essence, the golden rules, the rules of thumb, approaches or strategies do not differ all that much; each source lists a selection of DFE principles in a specific order, each having a specific perspective on the subject.

Furthermore, if we then compare the various sets of DFE strategies and principles listed in Figure 2.1 we see three different perspectives.

- The EPA, OTA and Smals sets of DFE strategies concentrate on DFE strategies 1 to 7. They do not include (aspects of) the @, New Business Concepts strategy, the strategy which is assumed to lead to more radical and innovative solutions. These sets are primarily intended to enhance the modification of existing products and processes. The focus on DFE strategies 1 to 7 will be called the 'evolutionary' perspective.
- Ryan and Manzini's sets of DFE strategies focus on DFE strategies 6, 7 and @. They do not include DFE strategies 1, 2, 3 and 4. The authors regard DFE strategies 1 to 4 as minor improvements and express their intention of concentrating on finding more radical and innovative solutions by taking a second look at how the product actually fulfils existing or presumed needs. This will be called the 'revolutionary' perspective.
- Finally, the perspectives used by Brezet et al. and by Zweers et al. have much in common. These give attention to modification of existing products and processes as well as more radical solutions which are represented by DFE strategy @ New Concept Development. These sets encompass many of the DFE principles defined in Van Hemel's typology of DFE strategies. They are distinguished as offering an 'integrated' perspective. The more recent sets of DFE strategies, published by Fussler and James (1996) and Cramer (1997), also offer the integrated perspective.

The aim of the DFE strategy typology developed for this thesis is to provide an exhaustive overview of the options for improving the environmental profile of a product throughout the different stages of its life cycle. The literature survey reported above shows that this aim is met by the DFE strategy typology developed by Van Hemel. All typologies found in literature on design for environment to date fall under the DFE strategy typology set out in the first column of Figure 2.1. This typology of DFE strategies was developed in 1994 on the basis of the literature and experiences available at that time (Van Hemel, 1994). More recently, Fussler and James (1996) and Cramer (1997) have also published specific sets of DFE strategies. Further analysis shows that these two new listings also fall under Van Hemel's typology, indicating that the DFE strategy typology is still complete and valid.
The typologies found in literature offer the evolutionary, revolutionary or integrated perspective. Since Van Hemel's DFE strategy typology offers the integrated perspective, it is assumed that it encompasses those DFE options geared towards the modification of existing products and processes as well as DFE options geared towards completely new ways of fulfilling a specific need, resulting in products or services with radically improved environmental profiles. Because of these characteristics, the DFE strategy typology was applied in the study reported in this thesis.

2.1.2 The objectives of the DFE strategy typology

The DFE strategy typology was developed with certain objectives in mind. As mentioned above, the main purpose was to provide those product developers who wish to integrate environmental demands into their product development with an overview of the different elements of DFE. This overview should be general and useful, regardless of the product undergoing (re)design. The typology should ensure that product developers are knowledgeable about the ins and outs of DFE and prevent them from simply selecting a certain DFE strategy which is not environmentally optimal, or which might possibly have an adverse environmental effect.

This implies that the DFE strategy typology should meet at least two basic requirements. Firstly, it should reflect the essential elements of design for environment, being the 'product life cycle approach' (all phases in the product's life cycle are looked at, as well as all the environmental effects in each phase) and the 'system approach' (not only is the product taken into consideration, but all the products and consumables required to make the product function properly as well). Secondly, the DFE strategy typology should be appropriate for the kind of product development practised in the company in question, and therefore link up, for example, to the company's specific product development process, the terminology used and the scarce environmental knowledge available. In the practice of product development it is quite common to work on the basis of a so called 'process tree' in order to achieve a complete overview of product requirements. This process tree has much in common with the product life cycle approach, an essential element of DFE. If the life cycle approach is safeguarded, then a simultaneous link is made with the process tree.

It is certainly *not* the intention that this typology should replace the methods that have been developed for DFE; it is the intention that it should complement them. It was not developed as a tool for DFE decision-making. Tools like Life Cycle Assessment (UNEP, 1996) and the MET matrix (Brezet et al., 1994) were already available to help decide which environmental problems related to a certain product are the most urgent ones. It is the intention of the DFE strategy typology to provide the product developer with ideas as to how he can resolve the environmental problems of a product.

2.1.3 The structure of the DFE strategy typology

In order to meet the requirements mentioned above the DFE strategy typology has been given the following characteristics.

Terminology for DFE strategies and DFE principles

To ensure their appropriateness in the practice of product development, the DFE strategies and principles are expressed in terms of design objectives with a positive environmental result. For instance: 'Reduce the energy consumption during use', rather than in environmental effects such as 'Reduce 20% of ozone depletion'. The latter would fail to give a product developer any ideas as to which of the product's aspects he could improve.

Clustering the DFE principles into DFE strategies

For them to be appropriate in product development practice, the DFE principles were clustered into DFE strategies in such a way that each cluster links up to a certain range of design decisions taken during the product development process. This is illustrated by the following example. Certain sets of DFE strategies (Brezet et al., 1994; Smals, 1993; Zweers and Van der Horst, 1993) make reference to the strategy of 'Energy reduction', meaning reducing the energy content of materials and the amount of energy used during production, distribution, consumption, etc. In the new DFE strategy typology the energy reduction issue is split up into various DFE principles, each being allocated to the DFE strategy related to the specific type of design decision in question. For instance: the DFE principle 'Low energy content material' belongs to the strategy 'Select low impact materials'. This is a useful solution since it makes it possible to balance the decision to use a material with a low energy content with other decisions concerning the selection of materials.

In order to signify the actual essence of DFE, the DFE strategy typology must reflect the system approach of DFE. In other words, those DFE principles that do not concern the product itself but which relate to the consumables required to make it function properly, are specified separately. The DFE principles that emphasize the system approach of DFE are 'Low/clean energy consumption during production', Few/clean production consumables', 'Less/clean/reusable packaging', plus all the five DFE principles that form the DFE strategy 'Reduction of impact during use'.

To avoid overlap where possible, the areas of interest for DFE have been clustered in eight DFE strategies. However, these DFE strategies are not completely independent: if an alternative type of material is selected, the applied production technique will probable alter as well. Whether a DFE improvement should be classified as belonging to DFE strategy 1 or to DFE strategy 3 depends on the main target of the DFE project and the core activity of the company involved.

Ranking the eight DFE strategies

In order to reflect one of the essential elements of DFE, the product life cycle approach, the DFE principles have been clustered into DFE strategies that can be ranked according to the subsequent phases in a product's life cycle. The specific ranking is explained in detail in the following section.

2.2 Description of the DFE strategies and DFE principles

The strategies are presented one-by-one below. The environmental benefits of the different strategies and principles are discussed in short as well.

2.2.1 DFE strategy @: New Concept Development

The symbol '@' has been attributed to the strategy of New Concept Development because it is of an entirely different calibre than the other seven strategies. The symbol refers to the Internet electronic mailing system (a highly innovative system, both from a functional and an environmental point of view). This strategy is used to develop new solutions for an existing specific need. The focus here is not on the existing, tangible product itself, but more specifically on the function and need fulfilment that underlies the product system. What societal need does the current product actually fulfil? Is it possible to develop an alternative product system which is able to fulfil the same need in a way which is less damaging to the environment? The decision to follow this strategy, especially principle @.1 (Substitution of (a part of) the product by an incorporeal service-provider) or @.2 (Shared use instead of product ownership), is in fact made prior to the product development process. Should a company decide to focus less on selling products and more on providing a service, then it is heading for New Business Development rather than New Concept Development: not only the product but the total product system is profoundly reconsidered. The strategy has much in common with what is referred to as 'sustainable product development' (Manzini, 1994; Van Weenen, 1994).

DFE principle @.1: Dematerialization

Dematerialization relates to replacing a material product with an immaterial substitute which still fulfils the need; not simply reducing the size of a product. This option often goes hand in hand with 'shared use of products'.

Examples:

- The Internet electronic mail facility offers an enormous improvement in the communication structure as well as a reduction in the amount of paper used, including fewer fax messages.
- The answering machines most of us have in our homes can be substituted by an answering service: the user calls the service provider, who passes on any messages left for him.

DFE principle @.2: Shared use of the product

For these improvement options it is assumed that if several people use a product jointly, without actually owning it, then that product is used more efficiently.

Example:

- Car-sharing systems have become popular In Switzerland and the Netherlands. In 1994 the Dutch Automobile Association (ANWB) launched a national Call-a-Car system. Subscribers pay an annual subscription in addition to the variable costs involved in using a car. This is a system in which approximately 15 people make use of one and the same car. It is obvious that these cars will need replacing far earlier than individually owned cars: a shared car lasts five years because of its intensive use, an individually-owned car lasts about 20 years. The environmental merit of shared use is that, thanks to the application of new, more environmentally-efficient technologies, the shared car can be replaced sooner by one which has a lower environmental impact. Repairs and maintenance are carried out by a central garage, i.e. on time and more efficiently. It has also become evident that people apparently adjust themselves to the new situation: they make less use of the car given that it is no longer parked outside the door. Alternative transport is often used for short journeys. This ANWB initiative has inspired about ten other Dutch organizations to set up comparable car-sharing schemes.

DFE principle @.3: Integration of functions

A great deal of material and space is saved through the integration of several functions or products into a single product.

Examples:

- Telephones, fax machines and answering machines can be substituted by integrated telephone-fax-answering machines.
- Notebook computers integrate a key-board, monitor and hard-disc into one, small computer.
- The use of a TV screen as a computer monitor in various applications.

DFE principle @.4: Functional optimization of product (components)

When reconsidering a product's main and secondary functions it might become evident that some of the product's components are superfluous. Also the (auxiliary) functions, such as the quality or status of the product, might be able to be realized in a better, less polluting way.

Example:

- The packaging of luxury goods, like make-up and perfume, are often oversized to give the product a 'high quality' look. This outward appearance reflecting the aspect of quality can also be achieved through intelligent and material-extensive design.

Rules-of-thumb for DFE strategy @:

There are no rules-of-thumb that can be given for this strategy since it provokes discussion on how the actual product system fulfils certain needs in society. That discussion can result in a redefinition of the business the company is involved in. This process can involve radical cultural, even organizational and structural changes. The decision to use this strategy is not in the hands of a project team, but is a matter for corporate long-term strategy.

2.2.2 DFE strategy 1: Select low-impact materials

The Select low-impact materials strategy focuses on the type of materials and surface treatments used. The aim is to select the most environmentally harmless materials for the product in question. Whether this strategy is practical or not depends to a great extent on the product's life cycle itself. Bronze, for instance, is a metal which is justified in the case of a sculpture which will be admired for many centuries, not for a disposable product. Moreover, it is easy to keep the sculpture out of the waste stream, to melt it down and reuse the metal at a later date.

DFE principle 1.1: Choose clean materials

Some materials and additives are better avoided since they cause hazardous emissions during production or when the product is incinerated or dumped. Examples of additives are: colorants, heat or UV stabilisers, fire retardants, softening agents, fillers, expanding agents and anti-oxidants. Some colorants and fire-retardants are particularly hazardous. In many countries certain toxic materials are prohibited by law. There is a debate about the use of organic materials (Van Hemel, 1997). Because they decompose naturally, organic materials are considered a good option if a product is unsuitable for recycling. However, if stored in landfill sites, for instance, the anaerobic decomposition of organic materials generates methane which is harmful to the environment.

Rules-of-thumb:

- Never use materials or additives which are prohibited on grounds of toxicity (see Van Hemel and Brezet (1997), module H, Product Oriented Environmental Policy, for a list of materials prohibited in various countries): these include PCBs (polychlorinated biphenyls), PCTs (polychlorinated terphenyls), lead (in PVC, electronics, dyes and batteries), cadmium (in dyes and batteries), mercury (thermometers, switches, fluorescent tubes) and the ozone layer-depleting halogenated CFCs (chlorofluorocarbons).
- Avoid ozone layer-depleting materials and additives such as halons (chlorine, fluorine, bromine), methylbromine, aerosols for coolants, plastic foams or solvents.
- Avoid hydrocarbons that cause summer smog (C_xH_y) for lacquers, solvents and plastic foams.
- Avoid surface treatment processes like hot-dip galvanizing or electrolytic zinc-plating and electrolytic chromium-plating.
- Find alternatives for non-ferrous metals, like copper, zinc, brass, chromium and nickel because of the harmful emissions released during their production.

DFE principle 1.2: Choose renewable materials

Materials must be avoided if they are not from sources which are replenished naturally, or from sources which take a long time before they are replenished (this is because such sources run the risk of becoming exhausted at a given time). Examples of such materials are: minerals, fossil fuels, tropical teak wood, copper, tin, zinc and platinum. Some scientists regard exhaustion as a minor environmental problem since such materials will ultimately become very expensive, be recycled, and alternative materials will subsequently be developed. Only the exhaustion of fossil fuels for generating energy is then regarded as a serious problem.

Rule-of-thumb:

- Find alternatives for exhaustible materials like minerals, fossil fuels, tropical teak wood, copper, tin, zinc and platinum.

DFE principle 1.3: Choose materials with a low energy content

Some materials have a higher 'energy content' than others, i.e. the extraction and production of these materials is very energy intensive. Use of these materials is only justified if they lead to other, positive environmental product features which are of real practical use in the product. For instance, while aluminium has a high energy content it is appropriate for use in a product which is often transported and for which there is a recycling system in existence. This is because aluminium is a light material and most suitable for recycling.

Rules-of-thumb:

- Avoid using energy-intensive materials like aluminium for short-lived products.
- Avoid using raw materials produced from intensive agriculture.

DFE principle 1.4: Choose recycled materials

Recycled materials are materials which have been used in products before. If suitable, use these materials a second time so that the energy gone into making the materials is not lost.

Rules-of-thumb:

- In order to increase the market demand for recycled materials make use of recycled materials wherever possible.
- Use secondary metals like aluminium and copper instead of their primary equivalents.
- Use recycled plastics for the inner parts of products which only have a supportive function and have no need for high quality in terms of mechanics, hygiene, or tolerance.
- If hygiene is important a laminate can be used; the centre of the laminate is made from recycled plastic, covered or surrounded with virgin plastic (e.g. in dispensable coffee cups or packaging);
- Make use of the unique features of recycled materials in the design (variations in colour, texture).

2.2.3 DFE strategy 2: Reduction of material usage

Reduction of material usage means striving to use the least possible amount of material by developing lean yet strong product designs. It also includes aiming for the lowest possible product volume so that the product takes up less space during transport. We often see products which have been designed too heavy or too large in order to project a certain image of quality. The same image can also be achieved through an intelligent design instead. Obviously, products should not be made so light as to affect their technical life.

DFE principle 2.1: Reduction of weight

Using less material is in fact a direct attempt to lower the product's environmental impact. It means less material, and consequently less waste. It also achieves a lower environmental impact during transport.

Rules-of-thumb:

- Aim towards achieving rigidity through clever construction instead of 'over-dimensioning' the product (e.g. make use of reinforcement ribs).
- Aim towards projecting quality through appropriate design instead of over-dimensioning the product.

DFE principle 2.2: Reduction of (transport) volume

A higher number of less bulky products (including the packaging) can be transported by a specific mode of transport. Another solution is to make the product foldable or 'nestable'.

Rules-of-thumb:

- Aim towards reducing the amount of space required for transport and storage by decreasing the product's size and total volume.
- Make the product foldable and/or suitable for nesting.
- Consider transporting the product in separate components that can be nested, leaving the final assembly up to a third party or even up to the end user.

2.2.4 DFE strategy 3: Optimization of production techniques

When selecting a production technique, focus on those which have a low environmental impact (i.e. a low consumption of non-hazardous auxiliary materials and energy), low losses of raw materials, and which generate the least amount of waste. Particularly when following this strategy a company should not limit itself to its own production processes but try to stimulate its suppliers to improve their processes as well.

DFE principle 3.1: Choose alternative production techniques

A DFE team does not always have the opportunity to choose alternative production techniques. If it does, it should always select production techniques with a low environmental impact.

Rules-of-thumb:

- Preferably choose clean production techniques that require fewer harmful auxiliary substances or additives (CFCs in the degreasing process, chlorinated bleaching agents).
- Select production techniques that generate few emissions, for instance: bending instead of welding, screwing instead of soldering.
- Choose processes which make the most efficient use of materials, like powder-coating instead of spray-painting.

DFE principle 3.2: Fewer production steps

Aim for the lowest possible number of production techniques.

Rules-of-thumb:

- Combine constituent functions in one component so that fewer production processes are required.
- Preferably use materials which require no additional surface treatment.

DFE principle 3.3: Low/clean energy consumption

This principle aims to reduce the energy consumption of existing production facilities.

Rules-of-thumb
- Motivate the production department and suppliers to make the processes energy-efficient.
- Get them interested in making use of sustainable sources of energy; (low sulphur content) energy sources are natural gas, low sulphur coal (anthracite), fermentation, wind energy, water power and solar energy.

DFE principle 3.4: Less production waste

The optimization of existing production processes in terms of production waste and material efficiency.

Rules-of-thumb:
- Design the product in such a way as to achieve the least possible amount of material waste (this applies particularly with regard to processes like sawing, turning, milling, pressing and punching).
- Motivate the production department and suppliers to reduce the amount of waste and percentage of rejects during production.
- Introduce in-company recycling for production residue.

DFE principle 3.5: Few/clean production consumables

This approach aims to reduce the amount of production consumables or operation materials required; these should also be composed of non-hazardous substances.

Rules-of-thumb:
- Reduce the required amount of production consumables (e.g. production facilities need cleaning less often if the product is designed in such a way to ensure that cutting operations do not result in mess from residual material).
- Consult with the production department and with suppliers on whether materials can be more efficient in the production process (good housekeeping, closed production systems, in-house recycling of production materials).

2.2.5 DFE strategy 4: Optimising the distribution system

Ensure that the most efficient transport is used to move the product from the factory to the retailer and then to the user. This relates to the packaging, the mode of transport and the logistics involved. The environmental impact of the distribution system used for the delivery of components should also be taken into consideration. If a project also includes looking at the aspect of packaging in detail, then packaging should be regarded as a product in itself, i.e. a product with its own life cycle.

DFE principle 4.1: Little/clean/reusable packaging

This is a case of preventing waste and emissions. The less packaging required, the greater the saving on material and energy consumption during transport.

Rules-of-thumb:
- If (part of) the packaging is intended to give the product a certain appeal, this can be realized by giving it an attractive but lean design.
- For transport and bulk packaging consider reusable packaging in combination with a deposit or return system.
- Use materials which are suitable for the kind of packaging concerned (e.g. avoid the use of PVC and aluminium for non-returnable packaging).
- Use the least possible packaging material, both in terms of weight and volume.
- Make sure the packaging enhances the reduced volume, foldability and suitability for nesting of products, as introduced in DFE principle 2.2 (small transport volume).

DFE principle 4.2: Energy-efficient means of transport

The environmental impact of transport by air is far greater than by sea. This must surely have an effect on the choice of transport method.

Rules-of-thumb:
- Encourage the sales department to avoid long distance transport by means of transport which are known to be harmful to the environment.
- Transport by container ship or train is preferable to road transport.
- Avoid transport by air.

DFE principle 4.3: Energy-efficient logistics

The environmental impact can also be reduced by making sure that whichever mode of transport is used it is loaded efficiently, and that the distribution logistics are efficient too.

Rules-of-thumb:
- Motivate the sales department to work with local suppliers if at all possible in order to avoid long distance transport.
- Motivate the sales department to introduce efficient distribution methods (e.g. distributing a larger number of goods at the same time instead of making several, smaller deliveries).
- Use standardized transport packaging and bulk packaging (europallets and standard package module dimensions).

2.2.6 DFE strategy 5: Reduction of the user impact

Consumables (energy, water, detergent, coffee) and products (batteries, refill cassettes, filters) are needed in the user stage for the product to fulfil its purpose. The same applies with regard to product maintenance and repairs. This strategy aims at designing the product in such a way that the user is unlikely to spill or squander materials, and/or searching for more environmentally-efficient consumables.

DFE principle 5.1: Ensure low energy consumption

The goal is achieving a reduction in energy consumption by choosing more energy-efficient components or by omitting certain components in order to reduce CO_2 (the greenhouse effect), SO_X and NO_X (acidification) emissions. Environmental analyses have shown that if a product consumes energy when used, it is usually at this stage that it has the most significant impact on the environment.

Rules-of-thumb:

- Use the lowest energy consuming components available on the market.
- Make use of a default power-down mode.
- Ensure that clocks, stand-by functions and similar devices can be switched off by the user.
- If energy is used for the purpose of moving the product, make the product as light as possible.
- If energy is used for heating substances, make sure that the specific product component is well insulated.

DFE principle 5.2: Choose a clean energy source

Making use of energy from a clean source of energy, especially for high energy consuming products, means a reduction in the total amount of environmentally harmful emissions.

Rules-of-thumb:

- Choose the least harmful source of energy (in the Netherlands this is natural gas, in France and Norway, electricity).
- Do not encourage the use of non-rechargeable batteries (e.g. a walkman can be supplied with a battery-charger, encouraging the use of rechargeable batteries).
- Stimulate the use of clean energy; (low sulphur content) sources of energy are natural gas, low sulphur coal (anthracite), fermentation, wind energy, water power and solar energy. For example: a solar heater which does not require gas or electricity to heat water during the summer months.

DFE principle 5.3: Reduce the amount of consumables required

The aim of this approach is to design the product so that it requires only a few, clean consumables for it to function properly.

Rules-of-thumb:

- Design the product so that the use of auxiliary materials is minimal (e.g. fit coffee makers with permanent filters instead of a filter system that requires paper filters, correct shape of filter to ensure optimal use of coffee).
- Prevent machines that use high volumes of consumables from leaking by installing a leak detector for instance.
- Study the feasibility of reusing consumables (e.g. a dishwasher that reuses the water).

DFE principle 5.4: Choose clean consumables

If there is a desire to improve a certain auxiliary product or consumable, it must be regarded as an individual product with its own life cycle. In that case, DFE strategies must the be selected separately for each product.

Rules-of-thumb:

- Design the product such that the cleanest available consumables will be applied.
- Ensure that use of the product does not result in an unnoticeable but harmful waste stream, e.g. by installing proper filters.

DFE principle 5.5: No waste of energy or consumables

A product can also be designed in such a way that it influences user behaviour. Users are encouraged to use products efficiently in order to achieve a lower consumption of additional materials and to reduce the amount of waste.

Rules-of-thumb:

- Misuse of the product as a whole must be avoided by providing clear instructions and semantic design.
- Design the product in such a way that the user simply cannot waste auxiliary materials (e.g. all inlets used for filling must be large enough).
- Use calibration marks on the product so that the user knows exactly how much auxiliary materials to use (e.g. washing powder).
- Make the default state the best one from an environmental point of view (e.g. 'beaker not dispensed automatically from drinks dispenser' or 'double-sided copies').

2.2.7 DFE strategy 6: Optimization of initial lifetime

The objective of this strategy is to extend the product's technical lifetime (the time during which the product functions well) and its aesthetic lifetime (the time during which the user finds the product attractive). This implies that the product will be used for its original function for a longer period of time. All the following principles belonging to this strategy strive to achieve the same goal: the fact that a product fulfils the user's needs for a longer period of time implies less inclination on the part of the user to purchase a new product. Occasionally it is better to refrain from extending a product's life; a new balance must be sought if a product's technical lifetime is much longer than its aesthetical lifetime. Either the technical lifetime must be made shorter or the aesthetical lifetime longer; the latter obviously has preference. A shorter life is preferred if new, less energy consuming alternatives are under development.

DFE principle 6.1: Increase reliability and durability

Increasing the reliability and durability of a product is a task which is familiar to product developers. The most important rule here is:

Rule-of-thumb:

- Develop a sound design and avoid weak links. Special methods like the Failure Mode and Effect Analysis are developed for this purpose (Pahl & Beitz, 1996, page 463-5).

DFE principle 6.2: Ensure easy maintenance and repairs

Easy maintenance and repair is important to ensure that the product will be cleaned, properly maintained and repaired in time.

Rules-of-thumb:

- Design the product in such a way that it needs little maintenance.
- Indicate on the product itself how it should be opened for the purpose of cleaning or carrying out repairs (e.g. where to apply leverage with a screwdriver to open snap connections).
- Indicate on the product itself which parts must be cleaned or maintained in a specific way (e.g. colour-coded lubricating points).
- Indicate on the product which parts or subassemblies must be inspected regularly because of fast wear and tear.
- *Make the places liable to wear and tear easy to detect, so that repairs or replacement can be made in good time.*
- Locate any parts liable to be worn-out relatively quickly close to each other so they are easy to replace.
- The most vulnerable components must be simple to dismantle for repair or replacement.

DFE principle 6.3: Ensure a modular, adaptable product structure

Choosing modular structure or adaptability makes it possible to 'revitalize' a product which has become substandard from a technical or aesthetical point of view, thus enabling the product to still meet the (changed) needs of the user.

Rules-of-thumb:

- Design the product in separate modules so that it can be upgraded simply by adding new modules/functions at a later date (e.g. plugging in larger memory units in computers).
- Design the product in separate modules so that it becomes possible to substitute (technically or aesthetically) outdated modules (e.g. seats and chairs with replaceable covers that can be removed, cleaned and eventually replaced).

DFE principle 6.4: Aim to achieve a classic design

The objective of this approach is to avoid trendy designs. Trendy designs lead to users replacing such products as soon as they become bored with the design or as soon as it goes out of fashion.

Rule-of-thumb:

- Design the product in such a way that it does not become uninteresting after a short while, thus making sure that the aesthetic life is not shorter than its technical life.

DFE principle 6.5: Ensure a strong product-user relation

Most products need a certain amount of maintenance and repair to keep them either looking good or in good working order. Users are only willing to spend time on such activities if they really care about the product. This approach strives to intensify the relationship between the user and his products.

Rules-of-thumb:

- Design the product such that it will more than meet the (possibly hidden) user's requirements for a long time.
- Ensure that maintaining and and/or repairing the product will be more of a pleasure than a pain.
- Give the product added value in terms of design and functionality so that the user will be reluctant to replace it.

2.2.8 DFE strategy 7: Optimization of the end-of-life system

A product's end-of-life system refers to what happens to it after its initial life. The intention here is to reuse valuable product components and to ensure proper waste management. Material cycles must be 'closed' if we are to reduce a product's environmental impact. This can be achieved by reusing the product as a whole, by reusing individual components, or by reusing the materials. If this is done, the materials and energy already invested in the product are simply reused to make the new product. By doing this the new product needs less material, less energy and it generates fewer hazardous emissions. If it is impossible to close the cycle, safe incineration and waste disposal must be guaranteed. Optimization of a product's end-of-life system is a strategy which should be considered in any development project.

DFE principle 7.1: Stimulate reuse of the entire product

The focus of this approach is to reuse the product as a whole, either for the same or for a new purposes. The more the product retains its original form, the more environmental merit is achieved as long as take-back and recovery systems are developed simultaneously. If the product has become technically obsolete (for instance: a new, more energy-efficient motor has been developed), this DFE principle is not recommended.

Rules-of-thumb:

- Give the product a classic design so that it does not become aesthetically obsolete or unattractive for a second user.
- Make sure that the construction is sound so that it does not become prematurely technically obsolete.

DFE principle 7.2: Stimulate remanufacturing and refurbishing

Many products end their lives in incinerators or as landfill, even though they might still have valuable components on board. The feasibility of reusing such components is definitely worthwhile considering, either for the same purpose or a completely new one. Remanufacturing or refurbishing the sub-assemblies is usually necessary when reusing components.

Rules-of-thumb:

- Design for dismantling (from product to sub-assemblies) so that the product is easy to inspect, clean, and repair, or that any sub-assemblies or components liable to wear out fast or become prematurely obsolete are easy to replace:
  - The product should have a hierarchical and modular design structure; the individual modules can then be removed for remanufacturing.
  - Use detachable non-permanent connections: form connections (e.g. snap or bayonet connections) or forced connections (e.g. screw fastenings) instead of welded, glued or soldered parts.
  - Use standardized connections so that only a few, universal tools are required to dismantle the product (e.g. use one type and size of screw).
  - Position all connections such that dismantling can take place without the need to turn the product around or move it.
  - Indicate on the product itself how it can be opened without damaging it (e.g. where and how to apply leverage with a screwdriver to open snap connections).
- Locate any parts liable to wear out relatively quickly close to one another so they are easily replaced.
- Indicate on the product itself which parts must be cleaned or maintained in a specific way (e.g. colour-coded lubricating points).

DFE principle 7.3: Stimulate material recycling

Several separate levels are involved in material recycling; collectively they are referred to as a 'recycling cascade': primary recycling (the recycled materials are then used for the same purpose as the original materials); secondary recycling (down-cycling: used for a lower-grade application); tertiary recycling (feedstock or chemical decomposition: decomposition of plastic molecules into elementary raw materials) (Nijkerk, 1995). If the materials are to be recycled, the product should be designed for disassembly and consist of recyclable monomaterials marked with the specific ISO code for purposes of identification.

Recycling is nowadays commonplace, particularly since it only involves a low investment, both in terms of time and money: design the product such that it is easy to disassemble and use suitable materials. Another reason why recycling is so popular is because it often gives rise to other (financial) benefits as well. The aspect of recyclability is also easy to communicate, both within the walls of the company itself and outside it. However, there has been a tendency to claim that a product is recyclable without attempting to establish a take-back and recycling system (or without even taking out a contract with an existing recycling organization). This trend is now less thanks to the increasing level of awareness. For example, the US Federal Trade commission prohibits such claims by law; a sound infrastructure must be in place and 'thermal recycling' is not regarded as recycling. If recycling is preferred above other strategies with a significantly greater environmental merit, above all, reconsider.

Recycling is an end-of-pipe solution which should never be used as an excuse to dispose of the current product in an 'elegant' manner.

Rules-of-thumb:

- If possible, give priority to primary recycling above secondary or tertiary recycling.
- Design for disassembly (from sub-assemblies to parts):
  - The product should have a hierarchical and modular design structure; the individual modules can then be removed, reused or recycled in the way most appropriate for the particular module.
  - Essential toxic materials should be concentrated in one place; this makes it possible for them to be removed easily.
  - Use detachable non-permanent connections: form connections (e.g. snap or bayonet connections) or forced connections (e.g. screw fastenings) instead of welded, glued or soldered parts, specially when incompatible or toxic materials need to be removed.
  - Use standardized connections so that only a few, universal tools are required to dismantle the product (e.g. use one type and size of screw).
  - Make sure that the product is as 'accessible' as possible, using the lowest possiblenumber of connections and position them such so that dismantling can take place without the need to turn the product around or move it.
  - Indicate on the product itself how it can be opened without damaging it (e.g. where and how to apply leverage with a screwdriver to open snap connections).
  - If it is impossible to take the product apart without damaging it, ensure disassembly in constituent material fractions is possible by incorporating breaklines so that disassembly results in fractions of only onetype or group of (mutually compatible) materials.
- Use recyclable materials:
  - Use recyclable materials for which collection systems are either in place or expected.
  - Use recyclable materials for which a market already exists or is expected.
  - Use thermoplastics, avoid compound materials, laminates, fillers, fire retardants and fibreglass reinforcements.
- Apply monomaterials:
  - Integrate as many functions as possible in a single part (a technique that can be used is called Value Analysis, see Pahl & Beitz, 1996)
  - Select just one type of material for the product as a whole or for the various sub-assemblies.
  - If it is impossible to use only one type of material, select mutually compatible materials (see the tables on compatibility of metals, plastics and glass/ceramics in Van Hemel and Brezet (1997), Module B, Optimisation of end-of-life system).
  - Avoid the use of polluting elements like stickers; these disrupt the recycling process.
- Mark any parts manufactured from synthetic materials with the appropriate ISO material codes and thus facilitate identification.

DFE principle 7.4: Stimulate safe incineration with energy recovery

If reuse and recycling is out of the question, the next best option is incineration with energy recovery (sometimes referred to as 'thermal recycling') as takes place in modern waste incineration plants. This process also ensures the recovery of certain metals.

Rule-of-thumb:

- *The higher the amount of toxic materials in a product, the more the party responsible has to pay for the incineration of that product.* It is therefore essential that toxic elements are located in one place, making them easy to remove and be treated as a separate waste stream.

DFE principle 7.5: Ensure the safe disposal of product scrap

It is essential that product scrap is disposed of correctly should it be absolutely impossible to reuse certain of the product's components, either by way of reuse, remanufacturing, recycling or energy recovery. Thanks to their biodegradability, it is claimed that biopolymers offer a solution here, yet environmental scientist have strong doubts as to the real and long-term environmental benefits of these polymers (Van Hemel, 1997).

2.3 From a typology of DFE strategies to the DFE strategy wheel

2.3.1 The DFE strategy wheel

Section 2.1 described the development of a typology of DFE strategies. It was argued that this typology was set up in an effort to develop a complete and useful typology of potential strategies that could be followed in the field of design for environment, while integrating the 'evolutionary' and the 'revolutionary' perspectives on DFE. The resulting typology of DFE strategies was used as a basis for developing a model called the DFE strategy wheel. This DFE strategy wheel (see Figure 2.2) was developed to increase the level of applicability of the DFE strategy typology in product development.

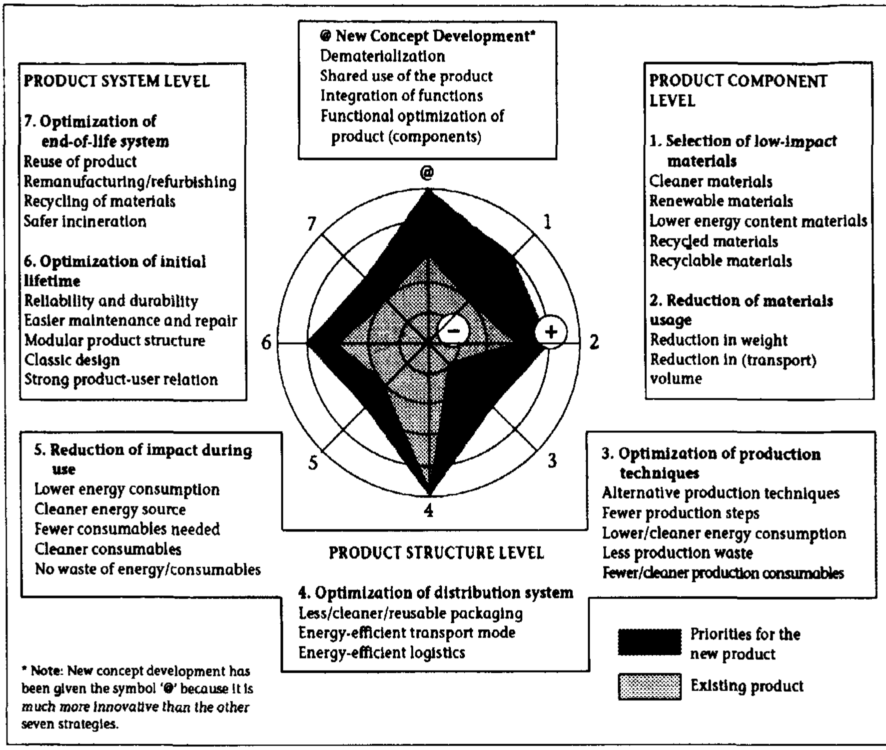


Figure 2.2 *The DFE strategy wheel (Van Hemel and Brezet, 1997, based on Van Hemel, 1994)*

If we compare the DFE strategy wheel shown in Figure 2.2 and the DFE strategy typology presented in the first column of Figure 2.1 we see that the clustering of DFE principles into DFE strategies, as well as their sequence, are identical. The DFE strategy wheel must be seen as an image and an elaboration of the DFE strategy typology.

What are the particular characteristics of the DFE strategy wheel? The thing that stands out most is that the eight DFE strategies are arranged in the form of a circle, the centre of which consists of a graph with concentric circles. The inclusion of this graph transforms the typology of DFE strategies into a tool that can be applied to draw up a picture of a company's DFE-related decision-making. The graph can be used to fill out the environmental profile of the product in question; an additional plane can be drawn showing the DFE priorities for the 'new' product. The DFE strategy wheel thus presents an overview of the DFE targets that should be aimed at reaching in the product development process. Other potential functions of the DFE strategy wheel in the product development process are explained in Section 2.3.3.

2.3.2 Strategy hierarchy in the DFE strategy wheel

The DFE strategy wheel emphasizes the hierarchy of DFE strategies. If we look at DFE strategies 1 to 7 in a clockwise direction, a parallel with the product life cycle is clearly visible: from material selection and processing, production, distribution and use, through to the so called end-of-life system. Given that the hierarchic arrangement of DFE strategies reflects the product life cycle, emphasis is laid on one of the essential elements of DFE: the product life cycle approach.

The general tendency is to regard DFE strategies 1 to 7 as 'improvement directions' (leading to environmental product system improvements) keeping within the framework of existing product concepts. Yet the DFE strategy @ is assumed to play another role: it does not draw heavily on the current product concept and its product life cycle, but serves to provoke discussion on how the existing product system fulfils the customers' needs.
From an environmental point of view the aim of DFE is to achieve structural and radical solutions which achieve a substantial reduction in the environmental impact in the longer term (revolution as opposed to evolution). DFE strategy @ 'New Concept Development' represents these far-reaching improvement options in particular. It is assumed that this strategy will open the door to the development of new product concepts which combine a highly innovative functioning with an outstanding environmental profile. Because of this particular feature, DFE strategy @, New concept development, has been given a special place in the DFE strategy wheel. The emphasis on the New Concept Development strategy in particular gives the DFE strategy wheel a somewhat normative character. This strategy was given the symbol '@' because it is of a different calibre than the other seven. The symbol refers to the Internet electronic mail system; a highly innovative system, both from a functional and an environmental point of view.

Nevertheless, this difference in the intentions of DFE strategies 1 to 7 on the one hand, and DFE strategy @ on the other should not be over-emphasized. The realization of various DFE principles encompassed by the 'evolutionary' DFE strategies (strategies 1 to 7) could imply a technical or organizational revolution for the company concerned. Moreover, they could even lead to revolutionary improved environmental product profiles as well. The extent to which a DFE strategy initiates evolution or revolution mainly depends on the type and life cycle of the existing product concept and on the environmental and innovational ambitions of the company in question.
Moreover, the relation between the product life cycle phases and DFE strategies 1 to 7 is not one-to-one. Some DFE strategies are relevant in several phases of the product's life cycle (Van Hemel and Brezet, 1997:143).

As required, the hierarchy is also appropriate for the practice of product development. By tradition (at least at the Faculty of Industrial Design Engineering at the Delft University of Technology), students are trained to work with the so called 'process tree' (Roozenburg and Eekels, 1995). To ensure that future product developers do not forget any product requirements they are trained to generate a complete set. They first of all draw up an inventory of all the product functions, following the subsequent steps of the process tree. Because the DFE strategy wheel reflects the product life cycle, it also reflects the process tree.

The sequence of DFE strategies in the DFE strategy wheel is in line with the practice of product development in another sense as well. If we follow the hierarchy of the DFE strategies in a counter-clockwise direction, from @, 7, 6 to 1, we see a parallel with the product development process. The product development process usually starts with a definition of the desired functions of the product system. This is followed by the development of the product concept, and finishes with a specification of the definitive production methods, product dimensions and the materials to be used (Roozenburg and Eekels, 1995; Andreassen and Heinen, 1987; Pahl and Beitz, 1996). To quote Pahl and Beitz: the subsequent stages in product development are 'Conceptual design', 'Embodiment design' and 'Detail design' (Pahl and Beitz, 1996).
This development process, from the generation of a product concept at *product system level*, via establishment of the functional structure at *product structure level*, through to the search for design options for product details at *product component level*, is reflected in the DFE strategy wheel. In this model, each DFE strategy is linked to one of the three levels distinguished; product system level, product structure level or product component level. The sequence of DFE strategies according to the development process implies that a sequence in terms of complexity can be identified regarding the realization of DFE strategies. Achieving a 'New business concept' is generally expected to be more complex than achieving a 'Reduction of materials'. Obviously, this sequence of incremental complexity is not the same for each product group. Considering the radical nature of the decision, the number of decision-makers required and the perceived uncertainty, we still assume that those DFE improvement options that influence the product component level only are easier to realize than those that influence the product system or product structure. In short: DFE strategy @ is thought to have a higher impact on the programme of requirements for a product system than DFE strategy 1.

It must be stressed that the DFE strategy wheel has some normative aspects too. As mentioned above, the DFE strategy @ New concept development has been given a special place in the wheel to highlight the importance of considering this strategy at the start of every product development process: go back to the actual need that the product fulfils and see if radically new options can be generated which fulfil that need in an innovative and more eco-efficient way. Another normative aspect is the place given to the DFE principle 'Recycling of materials'. This DFE aspect has been reduced to modest proportions and placed under the umbrella of the DFE strategy 'Optimization of the end-of-life system'. This has been done intentionally since DFE is all too often interpreted as 'Design for Recycling' (by entrepreneurs as well as researchers), while in fact it is an end-of-pipe solution rather than a prevention oriented solution (Van Hemel and Keldmann, 1996).

2.3.3 The functions of the DFE strategy wheel in the DFE process

The wheel can be used for different purposes and at different stages in the product development process.

Overview of DFE objectives

First and foremost the wheel serves as the frame of reference at the start of any product development process. It also provides an overview of possible DFE objectives. In turn, the overview prevents a product development team from taking one DFE objective only (and from holding on to that one objective) which might even be the wrong one to take anyway.

DFE creativity technique

Secondly, the wheel can be used as a DFE-oriented creativity technique. It has been a highly valued tool for generating ideas in various product development processes (Van Zuijlen, 1995; Van Hemel and Brezet, 1997; Böttcher and Hartman, 1997) to help systematically conceive options for improvement.

Visualizing DFE ambitions for a specific DFE project

Thirdly, both the company's managers and the development team can use the DFE strategy wheel as a tool to visualize a product's current, desired, and achieved environmental profile. The area in the centre of the DFE strategy wheel is then used to indicate which DFE strategies a product development team does or does not wish to focus on in both the short and long term. The outcome is a plan of action which ensures that all members of the product development team know exactly which aspects will be aimed for. The DFE strategy wheel enables a product development team to visualize, document and communicate the range of DFE strategies prioritized at the start of a product development project. However, it must be stressed that the model as such does not provide any support for decision-making on DFE; the planes can only be drawn if the company has a clear impression (qualitative or quantitative) of the actual environmental product profile.

The DFE ambitions (or DFE priorities) visualized in the model not only depend on the environmental profile of the product, but also on the commercial perspective as to which DFE strategies should and which should not be realized. The inner area indicates the extent to which the DFE strategies have already been applied to the product. The outer area indicates the DFE priorities set after balancing the environmental perspective with the business perspective. The difference between the outer position and the inner position of the lines that create the two surfaces indicates the DFE ambition for the specific DFE strategy. Each area is created by connecting the marks on the eight axes. The resulting area should not be interpreted mathematically; it simply gives an idea as to the type and number of DFE ambitions that underlie a specific product development project.

The process of setting DFE priorities, is described in the UNEP Ecodesign manual (Van Hemel and Brezet, 1997:67-88). The procedure was based on the RAILS approach: Readiness Assessment of Implementation of Life cycle design Strategies (Van Hemel, 1995). It highlights the role of the DFE strategy wheel as a technique to stimulate creativity in the process of DFE, and its role in visualizing the DFE ambitions for the specific product for both short-term and long-term realization.

2.3.4 Improving the DFE strategy wheel

The intention of the DFE strategy wheel was to visualize a generally applicable typology of DFE strategies and principles. The word 'typology' was preferred to 'classification, since in a classification the clusters must be mutually exclusive (Botter et al., 1994). Nevertheless, the intention was to create clusters of DFE principles that would be exclusive. From the experiences of users of the model (students, entrepreneurs, environmental experts) we can conclude that this goal was sufficiently met. However, it must be admitted that the structure of the DFE strategy wheel was sometimes less transparent than was intended. This is explained below.

Product component, product structure and product system level

For example, the model indicates that the main influence of DFE strategies 1 and 2 is on the product component level, that DFE strategies 3, 4 and 5 relate in particular to the product structure level and that DFE strategies 6, 7 and @ mainly have consequences at product system level. In practice, this distinction proved to be slightly too much of a generalization. It is true that DFE strategy 6 can result in a new service, maintenance or repair system, which is an improvement at the product system level since it goes beyond the tangible product. And indeed, optimizing the end-of-life system by reusing, remanufacturing or recycling is only worthwhile if the company develops a suitable take-back system. This is also an improvement at the product system level since it goes beyond the production and use of the physical product. However, it is clear that realization of strategies 6, 7 or @ also influences the product at the product component and product structure level.
This also applies vice versa. If an alternative material is selected for a certain product (related to the product component level in the model) it will also have consequences for the production techniques (related to the product structure level in the model). Despite this opaqueness, continuation of distinction of the three levels is recommended because of the normative element. Companies should be encouraged to aim for environmental product innovations and to reconsider the product system, not stick to minor environmental product modifications at product component level only.

Typifying DFE improvement options by using the DFE typology

In general, the DFE strategy wheel and its underlying typology of DFE strategies and principles were sufficiently transparent to typify any set of DFE improvement options. Occasionally, however, users of the model were not sure how they should categorize certain improvement options. They typified the option in another DFE principle than was intended. This was the case in the following improvement options:

- *Use monomaterials*: This option is not specified separately in the model since it is perceived as a means to reach the objective of 'Recycling of materials'. Use of monomaterials may have additional environmental benefits (less space required for stock; fewer suppliers; less transport), but the main target is to facilitate recycling. The recommendation here is not to specify 'monomaterials' separately.
- *Give the product a modular structure*: This option is specified separately. However, modularity is a means that suits at least three objectives: modularity can facilitate adaptability (function extension: adding new features to the product), repair (replacement of a defect subassembly) and disassembly (with the objective of reusing, remanufacturing or recycling a product). Where should modularity be typified? That depends on the objective of this improvement option. In the DFE strategy wheel the DFE principle 'modular product structure' was consequently replaced by 'modular/adaptable product structure'.
- *Improving surface treatments and glued connections*: Such improvement options can be typified under various DFE principles. Should surface treatments and glue be treated as a material or as a production technique? Where should the options be typified? Again, we recommend typifying the options according to their objective. The objective can either be to use alternative surface treatments/glue types (DFE strategy 1), or to use less surface treatment/glue by changing the product design (DFE strategy 2), or to use less surface treatment/glue by optimizing the production techniques (DFE strategy 3).

These issues must be explained when people first start to work with the DFE strategy wheel and they must be added to the description of the eight strategies.

Drawing the area in the centre of the DFE strategy wheel

One specific limitation of the DFE strategy wheel is that it is not always clear how the area in the middle should be drawn. Some users think the surface represents the product's actual and desired environmental load, i.e. that the surface should be as small as possible. However, the model is not intended to visualize the environmental load of a product, but the ambitions of the company or student at the start of a DFE project. The aim is to make the surface as large as possible. This problem was solved by adding the symbols (+) and (-) to the model, and by colour-coding the area representing the DFE ambition as 'Priorities for the new product'.

3. Operationalization of DFE performance

Chapter 3 describes how the performance in terms of design for environment of the SMEs that participated in the IC EcoDesign project was measured. The SMEs' DFE performance is operationalized by means of three indicators: DFE focus, DFE result and DFE learning.

3.1 Introduction

One of the aims of the study reported in this thesis is to measure, compare and explain the expected differences in DFE performance of the companies participating in the IC EcoDesign project.
To be able to find an answer to this question we first need an instrument that measures the actual DFE performance. A company's ***DFE performance*** refers to the extent to which the IC EcoDesign project has been responsible for initiating or enhancing a process of change, and had led to environmental concerns being integrated into the company's product development processes. This chapter explains how the instrument for measuring DFE performance was developed.

The most important requirements for the measuring instrument were:

- The measurement should be indicative of a company's DFE performance; in other words, the extent to which a process of change has been initiated or enhanced by the IC EcoDesign project.
- The measurement should result in a qualitative description of the focus within a company on DFE, reflecting the type and number of DFE improvement options it has prioritized.
- The measurement should result in quantitative information on the environmental improvement of the product in question as a result of the IC EcoDesign project.
- The measurement should result in quantitative information as to the extent to which the company will be able to apply DFE individually in future product development projects.

Information with regard to the third and fourth requirement should be quantitative so that statistical analyses can be made. These are for the purpose of assessing the relationship between the DFE performance indicators (as dependent variables) and a set of explanatory variables. To meet these requirements the approach chosen was to operationalize DFE performance by means of three indicators. In this thesis these are referred to as DFE focus, DFE result and DFE learning which, when combined, give an impression of the company's individual DFE performance as a result of the IC EcoDesign project (see Figure 3.1). Section 3.2 explains why this procedure was chosen. It would seem obvious in the field of DFE to measure the actual environmental product improvements by means of one of the existing DFE software tools available for life cycle analysis. Why an alternative, activity-based approach was preferred instead, is set out in Section 3.3.2.

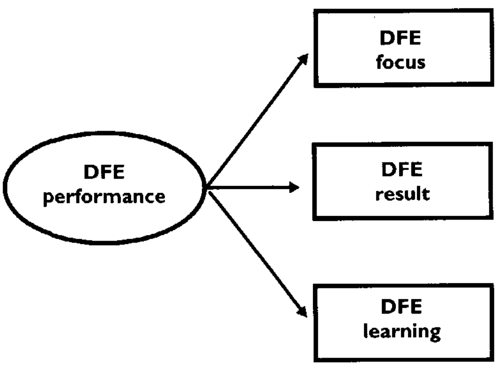


Figure 3.1 *The three dependent variables DFE focus, DFE result and DFE learning, operationalizing a company's DFE performance*

3.2 DFE focus, DFE result and DFE learning

DFE focus

An aim of this research is to gain insight into the companies' ***DFE focus***: the choices companies make with regard to how they apply DFE to their product(s). What DFE principles, suggested as a result of the IC Environmental Innovation Scan, did they actually implement and what was their motivation for doing so? Chapter 2 introduced the DFE strategy wheel as a typology of possible directions to pursue within the scope of DFE. It was explained that the DFE strategy wheel distinguishes 33 different DFE principles, clustered into 8 different DFE strategies. Since it offers an articulate frame of reference it was used in the Environmental Innovation Scan to classify the DFE improvement options the IC consultants had suggested. As a result, all options for DFE improvement were already typified according to the DFE strategy wheel. Therefore, it was only obvious that this classification should be used as one of bases for this study too.

Almost 600 DFE improvement options were suggested in the DFE action plans. A specific DFE principle, as typified in the DFE strategy wheel, was identified for each option. Classification was done in two subsequent steps. First, in order to structure his DFE action plan the IC consultant identified the DFE strategy that typified a specific DFE improvement option. Second, Van Hemel identified the actual type of option in more detail by distinguishing the DFE principle that typified the option in question. For instance, if the suggested DFE improvement option concerned selecting a non-toxic alternative for a certain toxic material, then the DFE principle was 'Clean materials' (DFE principle 1.1). The first figure refers to DFE strategy (DFE strategy 1: Selection of low-impact materials); the two figures combined refer to the specific DFE principle (DFE principle 1.1: Clean materials). Figure 3.2 illustrates the operationalization of the dependent variable DFE focus, the first aspect of DFE performance.

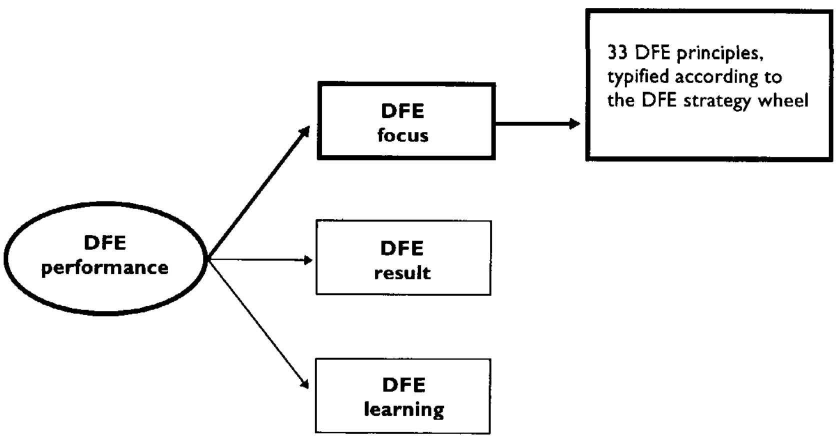


Figure 3.2 Operationalization of 'DFE focus', the first dependent variable of DFE performance

DFE result and DFE learning

The IC EcoDesign project can be referred to as an intervention programme intended to stimulate the application of DFE in small and medium-sized Dutch enterprises. Two types of results can be considered when assessing the outcome of a certain intervention programme, (Buijs, 1984; Argyris, 1994; Van Berkel, 1996). The first type of result concerns the actual improvements that have been achieved in the short to medium term (including packaging and production processes). The second type of result relates to how much the company has learned from the intervention, and whether it has developed routines which will enable the company to apply the newly learned principles in future projects. Together, these two results show the extent to which the intervention in question has either initiated or enhanced a process of change.

Buijs performed a study which aimed to describe, compare and explain the results of the Pii-b intervention programme in the Netherlands. This was a programme which was launched for the purpose of raising the level of product innovation in Dutch industry (Buijs, 1984). Buijs' study resembles this study with regard to structure. His approach was to measure the success of the intervention in terms of 'the definition of a new product idea' (referred to as the 'concrete results') and the routines developed in the company (referred to as 'internalization' or the 'learning effect'). Buijs distinguished four degrees of success achieved by an intervention project; the definitions are explained in Figure 3.3.

Aspect	**Score**			
Concrete results	+	+	-	-
Internalization	+	-	+	-
Project results	++	+	-	- -

Score: + = present; - = not present

Figure 3.3 *Scoring of the project results of the Pii-b innovation intervention programme, divided over two sub-results (Buijs, 1984)*

In Buijs' study, the data required to identify the concrete results and internalization were gathered by means of pre-structured questionnaires, completed during interviews with the top management of 79 companies in person. Buijs' operationalization of the dichotomous indicators was:
Concrete results: (+) if the company stated that the project had resulted in a new product idea;
Concrete results: (-) if the company stated that the project had not result in a new product idea;
Internalization: (+) if the company stated that it had learned how to innovate;
Internalization: (-) if the company stated that it had not learned how to innovate.

The results of the present study, which focuses on the DFE performance of SMEs participating in the IC EcoDesign project, will also be expressed in terms of concrete results (referred to as the DFE result) and internalization (DFE learning). Together, they show the extent to which a process of change in the direction of DFE has been initiated. This is the only parallel with Buijs' study because of the following reasons. First, in this DFE performance research the result is measured at a later stage in the product development process than was the case in the Pii-research. This meant that the actual product improvements could be measured in the present research. The criterium for concrete result in the Pii-research was whether the company had, or had not defined a new product concept. Second, in the present research the focus is on typifying and measuring the environmental improvements of the product; this was not the case in the Pii-b study.

Another relevant study was performed by Van Berkel (1996). Van Berkel measured and compared the results of four different intervention programmes which set out to improve cleaner production in industry. Taking a similar approach as Buijs, he distinguished the concrete results and the learning effects of these four intervention programmes. The concrete results were described as "the implementation of the comparatively obvious cleaner production opportunities in the short term". The learning effects were described as "the creation of favorable conditions for sustaining and expanding the environmental improvements in the longer term". The aim of Van Berkel's study was to compare the results of the four cleaner production intervention programmes. The target of the present study is to compare the DFE performance of the individual companies participating in a single DFE intervention programme. Because of that, the methods for measuring the results developed by Van Berkel could not be applied in the study reported on in this thesis. Nevertheless, the fact that both Buijs and Van Berkel distinguished concrete results and learning effects, gave support to the approach chosen in the present study.

3.3 How to measure a company's DFE result?

How can we measure the ***DFE result***, or in other words the concrete environmental product improvements, of a company that participated in the IC EcoDesign project? This question is answered in the following sections. First of all we look at which of the existing approaches could be of use, before going on to explain the method for measuring DFE results as developed in the present study.

3.3.1 Existing approaches as described in environmental management literature

How to identify the attitude, performance or the progress achieved by companies in terms of environmental issues has been addressed in various publications. Literature about environmental management tells us that many authors developed conceptual models to identify the extent to which companies managed to integrate environmental concerns in their corporate business strategies. Overviews and comparisons of the various typologies of environmental management are known from Hass (1996), Green and McMeeking (1997) and Mauser (1996). Hass (1996:61) compares five *Continuum environmental management strategy models/typologies* of Hunt and Auster (1990:9), Greeno (1993:17), Newman (1993:32), Müller and Koechlin (1992: 166-172) and Roome (1992:18). Green and McMeeking (1997:3) give a summary of *Strategic Options or Stages in response to the Environmental Challenge* (adapted from Lee and Green, 1994, with additions from Hass, 1994). In addition to Hass' overview he included the typologies given by Sadgrove (1992), Steger (1993), Chatterji (1993), Winsemius and Mak (1994), Ledgerwood et al., (1992), Peattie and Ratnayaka (1992) and Lee and Green (1994). Mauser (1996:4) developed an overview of *Different models of the process of integration of environmental issues in company strategies.* To the typologies mentioned in the foregoing, she added the typologies given by Petulla (1987), Hofstra et al. (1990), Meffert and Krichgeorg (1993), Schot (1995), Elkington (1995), Molenkamp (1995), Veering (1995), Welford (1995) and Cramer and Jansen (1995).

Mauser's criticism of the models is comparable with the criticism of Green and Hass. An essential element of Mauser's criticism is that these stage models are actually intuitively-based classifications which fail to meet the requirements for a correct classification as described by Doty and Glick (1994). The stages do not exclude one another. This implies that classification of a company is by no means obvious and therefore the models have little practical value. A criticism expressed by Hass is that these models are prescriptive rather than descriptive (Hass, 1996). It has not been studied thoroughly whether these strategies exist in practice or not. Furthermore, Mauser states that the models are not as dynamic as they would seem. It is quite possible for the various business units of one company to be classified in different stages. Moreover, the environmental attitude among the managers could easily change over time (Mauser, 1996:5).

The opinions of Hass, Green and Mauser on the practical value of the typologies is clear: they offer a conceptual framework for identifying the corporate attitude towards environmental issues or how far they have progressed with environmental management. However, they have been insufficiently empirically tested and are generally poorly operationalized. To be able to measure the DFE result for this study we need a measuring instrument which is more refined and more product-oriented than the models discussed above. Instead of identifying attitudes or stages of environmental awareness, we want to take a quantitative measurement of the actual performance in the field of DFE.

3.3.2 Applicability of DFE tools for life cycle analysis

Life cycle analysis tools play an important role in the field of DFE. In short: a life cycle analysis is used to assess the environmental profile of a product system in all the stages of its life cycle. The environmental benefits of a redesigned product can be assessed by constructing an environmental profile of the redesign and comparing it with the environmental profile of the reference product, e.g. the original design or a competitive product. These environmental profiles can be constructed by using a method for life cycle analysis: either a qualitative one (like a MET Matrix, see Brezet et al., 1994) or a quantitative variant (like a Life Cycle Assessment, see SETAC, 1993; UNEP, 1995; Van Hemel and Brezet, 1997; Hanssen, 1997). Identifying the environmental product profile implies that not only the tangible product is studied, but that the total functional product system is also taken into consideration. Furthermore, it is essential not to focus on one stage in the product's life cycle alone, but to consider all the various life cycle stages as a whole. DFE tools for life cycle analysis, developed for the specific purpose of assessing a product's environmental profile, are apparently suitable for measuring the DFE result of the SMEs participating in the IC EcoDesign project. Their applicability in the present study is discussed in the following.

DFE tools for life cycle analysis enable us to analyze the environmental effects of a product system in all phases of its life cycle. Therefore, they are referred to as DFE tools for *life cycle* analysis. There are various types of DFE tools for life cycle analysis. They all have in common that they assess all possible environmental effects of a product system in all stages of its life cycle. A different type of DFE tool is to be found in the category of tools that focus on a specific stage in the product life cycle. Examples are the computer tools *ReStar* (Navin-Chandra, 1993) and *DFE* (by TNO/Boothroyd Dewhurst, see Kalisvaart and Van den Broek, 1996) both focusing on the product's end-of-life phase. Since these tools fail to look at the total life cycle, they will not be included in this thesis.

DFE tools for life cycle analysis can be identified on the basis of two of their specific characteristics: their level of quantification and the number of environmental effects considered. Firstly, the tools for life cycle analysis differ initially in the extent to which they are quantitative and information-intensive (like a Life Cycle Assessment) as opposed to qualitative and information-extensive (like the MET Matrix). In this thesis the expression ***life cycle analysis*** is used specifically to refer to the whole group of methods or tools for making life cycle analyses, either qualitatively or quantitatively. The expression ***Life Cycle Assessment*** is reserved here for computer tools which can be used for making a quantitative, detailed life cycle analysis or Life Cycle Assessment.
Secondly, the tools for life cycle analysis differ in the extent to which they set out to consider all possible environmental effects, a selection of effects or just a single effect (TU Delft, 1996).
Examples of tools to assess all environmental effects are the MET Matrix (Zweers and Te Riele, 1995; TU Delft, 1996; Van Hemel and Brezet, 1997), computer programs for Life Cycle Assessment (SETAC, 1993; UNEP 1995; Van Hemel and Brezet, 1997) and the Eco-Indicator 95 (Goedkoop, 1995). An example of tools that look at a selection of environmental aspects is the MIPS method, developed by the Wuppertal Institute, in which the focus is on a product's material intensity per unit of service (Hinterberger et al., 1994). Another example of tools that focus on one environmental effect only is the Energy Indicator (TU Delft, 1996).

It is widely acknowledged that DFE tools for life cycle analysis are of high value in the design for environment process (CREM, 1994; SETAC, 1993; Cramer, 1993; Hanssen, 1997). The most important benefit offered by tools for life cycle analysis is that they make it possible to draw a picture of the environmental bottlenecks of a product system. In most cases they reveal in what stage of the product life cycles the main environmental problems arise; they also identify the nature of the main environmental problems. Tools for life cycle analysis give reliable results if two products, which differ on certain product details only, are compared. Hanssen (1997) states that only by conducting a quantitative Life Cycle Assessment (LCA) is it possible to create a sound picture of the environmental problems of a product system. Moreover, an LCA reveals the gaps in environmental know-how concerning the product system involved, makes DFE decisions 'transparent' and exposes the uncertainties involved in certain DFE decisions (Hanssen, 1997).

However, it is widely accepted that tools for life cycle analysis do have their limitations as well (Cramer, 1993; CREM, 1994; Goedkoop, 1995; Cramer 1996). What then are these limitations? And do these limitations impede their application in the study reported in this thesis? Some of the limitations are described in the following; most of them are related more to Life Cycle Assessments (being comprehensive, detailed and quantitative) than to the more qualitative methods for life cycle analysis. However, it is impossible to make a life cycle analysis without any quantification at all. Therefore, the following selection of limitations applies with regard to all life cycle analysis methods in general, and to Life Cycle Assessments in particular.

1. One of the main limitations of tools for life cycle analysis is their methodological complexity (Cramer, 1993). They require not only an analysis of the tangible product; the total functional product system should also be taken into account. Furthermore, it is essential not to focus on one stage in the product's life cycle only, but to consider all life cycle stage as a whole. A vast amount of information is needed; the analysis method is rather sophisticated. The result is that it takes

newcomers in the field of life cycle analysis a long time to learn how to make a life cycle analysis. This limitation is particularly strong in the case of a Life Cycle Assessment.

2. A great deal of time goes into a life cycle analysis. Most of that time is spent on tracking down the necessary (usually not readily available) environmental information. Information required from abroad is particularly difficult to obtain (CREM, 1994). Attempts have been made to set up data banks to gather general data for specific industries, products and materials (Cramer, 1996). An example of such a data base is IDEmat, developed by the Delft University of Technology (Remmerswaal, 1996). This data base combines environmental data on materials, components and processes with other engineering data which can be of value in the product development process. However, companies are unable to rely on data banks since they generally have a need for corporate or at least regional data (CREM, 1994; Cramer, 1996). For some processes, like energy generation and transport, various dissimilar sets of data are available and it can sometimes be difficult to know which data set to apply. One of the reasons for this is the lack of criteria for evaluating the quality of a specific data set (CREM, 1994).
3. As a consequence of the vast amount of information required, all partners playing a role in the product life cycle must be willing to cooperate. They must be willing to provide information about their activities and to spend time in searching for and providing the necessary environmental data.
4. Another limitation is the dynamic character of life cycle analysis (Cramer, 1993). The format and results of a life cycle analysis depend much on the initial problem definition which can do no other than include some decisions which are arbitrary and liable to changing perspectives. Moreover, environmental data are dynamic too. The scientific opinion on the seriousness and intensity of certain environmental effects has not yet been crystallized and may change over time; nor is the societal perspective on this subject constant.
5. Finally, the results of life cycle analyses are difficult to interpret (Goedkoop, 1995). The environmental effects can be identified by making a life cycle analysis, e.g. the contribution towards depletion of the ozone layer. However, there is no valuation system that makes it easier to weigh the various environmental effects. In other words: it is impossible to define the total environmental load.

In an effort to overcome some of the limitations mentioned above so-called 'abridged' tools for life cycle analysis have been developed. Well-known in the Netherlands is the MET Matrix (Zweers and Te Riele, 1995; Van Hemel and Brezet, 1997), a matrix that structures evaluation of the aspects of Material (loops), Energy and Toxic emissions throughout a product's life cycle. Another abridged life cycle analysis tool is the MIPS method (Hinterberger et al., 1994). This MIPS method includes all the phases in a product's life cycle, yet it does not include all the environmental effects. The focus is clearly on material inputs (minerals, water, air, biomass). It is a method which does not include the eco-toxicity of materials, land-use, entropy changes or the impact on biodiversity (Hinterberger et al., 1994). A third abridged tool for life cycle analysis is the Eco-Indicator 95. This consists of data sheets with a hundred so-called eco-indicators for materials, processes, distribution systems and recovery or waste treatment systems, as well as calculation forms for calculating a product's environmental profile. It assesses all stages in the product's life cycle and all environmental effects (exhaustion of materials excluded) (Goedkoop, 1995). In contradiction to most tools for life cycle analysis, the MIPS method and the Eco-Indicator 95 result in a single factor for the environmental load of a product system. Computer versions of the Eco-Indicator method were recently released under the names EcoScan (Wielemaker, 1997) and Eco-It (Goedkoop, 1997).

Performing a life cycle analysis using one of the abridged tools described above is generally less time consuming than performing a fully detailed Life Cycle Assessment. The first, second and third limitations discussed above are less influential in the case of abridged life cycle analyses than in the case of Life Cycle Assessments. The fourth and fifth limitations are equally as influential for both abridged life cycle analyses and Life Cycle Assessments. However, the more abridged a method, the more assumptions are included and, as a consequence, the more we should doubt the correctness of the conclusions of the study.

With respect to the study reported in this thesis it was decided to perform neither Life Cycle Assessments nor to apply an abridged tool for making life cycle analyses. This decision was taken because the combination of the above limitations of DFE tools for life cycle analysis would, in combination with the setting of the IC EcoDesign project, impede their meaningful application in this research. In short, the preconditions for using DFE tools for life cycle analysis in a comparative corporate study are the following:

- there should be ample time available,
- all companies must be willing to cooperate and
- all (re)designs studied must have reached such a stage in the development process that the exact dimensions, materials, processes, etc., are known.

Because of the settings of the IC EcoDesign project and the DFE performance study none of these requirements were met. Therefore, DFE tools for life cycle analysis would be unproductive.

The conclusion regarding the applicability of DFE tools for life cycle analysis is as follows. DFE tools for life cycle analysis are too refined and information-intensive for application in this study which must measure the DFE performance of as many as seventy companies. An alternative method for measuring the DFE result of the SMEs participating in the IC EcoDesign project is necessary. The following section explains the method of measuring the companies' DFE result developed for the present study.

3.3.3 A method for measuring DFE result

The question is how to measure the extent to which a process of change (in the direction of DFE) has been initiated or enhanced by the IC EcoDesign project. The obvious thing to do was to make two life cycle assessments, one of the old product and another of the environmentally improved product. However, because of the various reasons explained above, the existing software tools for life cycle analysis were of no use in this study.

The approach preferred was to measure to what extent a process of change in the direction of DFE had been initiated or enhanced by means of a process-based or activity-based approach. The method for measuring the SMEs' DFE result is based on an evaluation of how far the DFE improvement options that were suggested have in fact been implemented. In literature, this is referred to as an activity-based approach, working with semi-quantitative indicators that measure a company's efforts in the field of prevention of environmental load (Jakobs and Cramer, 1995). As such, it resembles the evaluation methods that were applied in comparative studies on the effectiveness of cleaner production programmes (Van Berkel, 1996; Bosveld et al., 1995).

A company's DFE result reflects the extent to which the product involved (including processes and packaging) had actually been improved environmentally as a result of the IC EcoDesign project. The DFE result of an individual company is assessed by using a set of four DFE result indicators. These four DFE result indicators are called ***DFE score***, ***DFE project score***, ***DFE design impact*** and ***DFE result opinion***. Figure 3.4 summarizes the contents of each of these four DFE result indicators. They are explained one-by-one below.

DFE result indicator	Description
DFE score	The extent to which a set of DFE improvement options (suggested in the DFE action plan generated through the IC EcoDesign scan) have been implemented.
DFE project score	The extent to which a set of DFE improvement options with a high level of newness (suggested in the DFE action plan generated through the IC EcoDesign scan) has been implemented.
DFE design impact	The researcher's opinion on the degree of innovation achieved for the product involved in the IC EcoDesign Scan.
DFE result opinion	The opinion of the company's representative as to how much the IC EcoDesign project has led to concrete results for the product involved.

Figure 3.4 The four DFE result indicators and their meanings

DFE score

The point of departure for measuring a company's DFE score is the DFE action plan. This plan results from the Environmental Innovation Scan made in the first step of the IC EcoDesign project. The DFE action plan consists of a set of DFE improvement options which are typified according to the DFE strategy wheel. A total number of 1 to 15 DFE improvement options were suggested to each company. To measure a company's DFE score the following aspects of the suggested set of DFE improvement options were assessed systematically during interviews which were carried out over the telephone:

1. The number of DFE improvement options suggested in the DFE action plan;
2. The extent to which each option had been implemented (referred to as the option 'success rate');
3. The extent to which each DFE option was new for the company (referred to as 'newness').

At the time when DFE performance was measured, a total of nine different success rates were distinguished. This is illustrated in Figure 3.5.

Cluster	Success rate	Description
Rejected	0	The option had been rejected; moreover it was of no future interest to the company
Of interest	1	The option had been studied in more depth; realization had still been rejected
	2	The option had not yet been studied; it was assured of the company's future interest
	3	The option was still being studied; realization was still not certain
Prioritized	4	The option was being implemented; realization was expected within three years
	5	The option was being implemented; realization was expected within one year
	6 (Realized)	The option had already been implemented or would be implemented very soon
Not considered	7	The option had not been given special attention as it was regarded as a bottom line in product development and therefore has the company's continuous interest
	8	The option had not been studied because it had become irrelevant

Figure 3.5 The nine success rates (0 to 8) reflecting the extent to which a DFE improvement option had been implemented when the study took place

As Figure 3.5 shows, the success rates are clustered into four groups. The first group contains rate 0 only, implying that this option was ***rejected*** without any study. The second group includes rates 1, 2 and 3, indicating that the company had shown some ***interest*** in the option, but without much success to date. Stimulated by the IC EcoDesign project the company had undertaken at least some DFE-related activity in terms of these options. The third group clusters rates 4, 5 and 6. Options attributed with one of these success rates are said to be ***prioritized***. Only options with success rate 6 are actually ***realized***. With respect to options attributed with a success rate of 4, 5 or 6, the company concerned had made a considerable effort to finally implement the suggested options.

Finally, the fourth group, success rates 7 or 8, is marked as ***not considered***: the options fall beyond the range 0 to 6 in the sense that they should be classified as neither rejected nor of interest nor prioritized. In measuring the DFE score, DFE improvement options marked with a success rate 7 or 8 were not taken into account any further. It was decided to filter out options marked with rate 7 given that the companies regarded them as being not DFE-specific but rather as the indispensable 'bottom line' for proper product development. This was the case, for example, with regard to options like 'Reduce the number product components'. Options given success rate 8 were filtered out because they simply had become irrelevant. This, for example, could be the case if an option was suggested for a certain sub-assembly, even though that sub-assembly had already been eliminated from the design at the moment the measurement was taken.

A company's DFE score is thus defined as the extent of implementation of the set of DFE improvement options suggested in the DFE action plan as a result of the IC EcoDesign scan. The DFE score is calculated by the formula:

$$\text{DFE score} = R_1 + R_2 + \ldots + R_n = n * Rg$$

R_1 : The success rate of option 1

n: The number of DFE improvement options listed in the DFE action plan

Rg: The average success rate of the DFE improvement options

DFE project score

The aim is to measure the DFE performance achieved by the companies as a result of the IC EcoDesign project, or in other words: the project's 'added value'. However, the DFE score (calculated on the basis of the above formula) does not distinguish between DFE options which are completely new for the company and those DFE options the company would have considered anyhow. For this reason, a second DFE result indicator has been constructed, called the DFE project score. While this DFE project score is calculated similarly to the DFE score, it is based exclusively on the DFE options that were considered as a result of the IC EcoDesign project. In this study, three degrees of DFE option 'newness' are distinguished; they are presented in Figure 3.6. For example, the added value of the project is limited if most of the DFE improvement options studied had a newness of 1; they would have been considered regardless of the project.

Newness	Description
1	The company would have studied or implemented the DFE improvement option even if it had not participated in the IC EcoDesign project; newness here is limited
2	The company had been considering the DFE improvement option, but without the IC EcoDesign project it would not have considered it any further; newness here is fair
3	The DFE improvement option was totally new for the company; the newness here is high

Figure 3.6 *Three degrees of newness, reflecting the extent to which a company was already familiar with the DFE improvement option in question*

A company's DFE project score is defined as the extent to which a set of DFE improvement options with a high degree of newness (newness 2 or 3), suggested in the DFE action plan as a result of the IC EcoDesign scan, was implemented. The DFE project score is calculated by using the formula:

DFE project score = $A_1 + A_2 + ... + A_m = m * Ag$

A_1: The success rate of option 1 (only options with newness 2 or 3)

m: The number of DFE improvement options listed in the DFE action plan (only options with newness 2 or 3)

Ag: The average success rate of the DFE improvement (only options with newness 2 or 3).

The resemblance between the formula for DFE score and that for DFE project score is obvious. The difference is that to calculate the DFE score all DFE options are considered, while for the DFE project score the DFE options with newness 1 are excluded. To prevent confusion, the letter 'R' was changed into an 'A', and 'n' into 'm'.

3.3.4 Elaboration of the proposed operationalization of DFE result

The basic approach for measuring the DFE result as presented in Section 3.3.3 is elaborated upon further and completed in this section. The DFE score was measured provisionally by assessing the number of suggested DFE improvement options and their individual success rates. Dieleman (1991) states that the number of prevention options only is by no means an unequivocal parameter. There are several reasons for this, one of them being that simply counting the number of options does not distinguish between their relative importance in terms of innovational character or environmental benefit. It must be admitted that the presently proposed method for measuring the DFE score also has the same limitation. Therefore, certain measures are taken to overcome this limitation where possible.

The first improvement is that in the assessment of DFE score (DFE score = n * Rg) the average success rate of suggested DFE improvement options will be stressed at the expense of their number. The emphasis is created by including the factor Rg twice in the formula for DFE score (DFE score = n * Rg * Rg). The second improvement is to accompany the DFE result indicators DFE score and DFE project score by two additional indicators: the so called 'DFE design impact' and the 'DFE result opinion'. The DFE design impact variable indicates the degree of innovation of the selected product to which the DFE principles had been applied. The DFE result opinion variable reflects the company representative's opinion as to how much the IC EcoDesign project has led to concrete results for the product involved.

Stressing the average success rate of DFE improvement options

The table shown in Figure 3.7 can be generated by using the provisional method for measuring the DFE score (DFE score = n * Rg) suggested in Section 3.3.3. In the figure we see that company A has focused on two DFE options only and managed to realize one (success rate 6); it will very soon realize the other option (success rate 5). The approach taken by company B was less focused; while it considered 5 options it still failed to implement them in full. The DFE score of both companies adds up to 11. However it is far better to 'realize' a small set of DFE improvement options than to 'consider' many of them. In other words: the DFE score of company A should be valued higher than the result of company B. To achieve this, the average success rate will be emphasized more than the number of suggested DFE options. The proposal therefore is to square the term 'Rg' in the formulas (mentioned in 3.3.3). The result of this correction is also illustrated in Figure 3.7.

Company	Number of options (n)	Average success rate (Rg)	Provisional DFE score (n*Rg)	Corrected DFE score (n*Rg*Rg)
Company A	2	5,5	11	61
Company B	5	2,2	11	24

Figure 3.7 Comparison of the DFE scores of two companies; squaring Rg emphasizes that company A has achieved a higher average success rate (with a limited number of options) than company B (which has a higher number of options)

The result is that the two formulas for calculating DFE score and DFE project score change as follows.

A company's **DFE score** *is defined as the extent to which the set of DFE improvement options (suggested in the DFE action plan as a result of the IC EcoDesign scan) have been implemented. The DFE score is calculated by using the formula:*

$$DFE\ score = n * ((R_1 + R_2 + ... + R_n)/n)^2 = n * Rg * Rg$$

- R_1 : *The success rate of option 1*
- n: *The number of DFE improvement options listed in the DFE action plan*
- Rg: *The average success rate of the DFE improvement options*

A company's **DFE project score** *is defined as the extent to which a set of DFE improvement options with a high level of newness (newness 2 or 3) (suggested in the DFE action plan as a result of the IC EcoDesign scan) has been implemented. The DFE project score is calculated by using the formula:*

$$DFE\ project\ score = m * ((A_1 + A_2 + ... + A_m)/m)^2 = m * Ag * Ag$$

- A_1 : *The success rate of option 1 (with newness 2 or 3)*
- m: *The number of DFE improvement options (with newness 2 or 3), listed in the DFE action plan*
- Ag: *The average success rate of the DFE improvement options (with newness 2 or 3).*

The formulas for measuring a company's DFE score and DFE project score are thus based on the average success rate of a set of DFE improvement options. However, there is a certain element of risk attached to working with averages. For instance: a company has been suggested with a large number of DFE options (6 for example), some of which have been implemented (2 for example). The company might then be faced with the problem of a low average success rate because it had deliberately selected certain options on which to focus. In consequence, high success rates could be negated when averaged because of the low success rates of the other options. In figures: if a company is suggested 6 DFE options, of which only 2 are realized, than the DFE score is 12 (6+6+0+0+0+0) with an average success rate of 2 (12/6). Whether this effect actually is a problem will be assessed in Chapter 5 by means of empirical data.

In the foregoing we suggested calculating a company's DFE by using the formula $DFE\ score = n * Rg^2$. Greater emphasis has been put on the factor 'Rg' intentionally than on the factor 'n' in this formula. But why not stress 'Rg' even more by applying the formula $DFE\ score = n * Rg^3$? In other words, does the adjusted formula 'DFE score = $n * Rg^2$' offer a more reliable scale to measure the DFE score than the formula 'DFE score = $n * Rg^3$'? In order to compare the two measurement scales a correlation analysis will be carried out on the basis of empirical data. The results will be discussed in Chapter 5.

DFE design impact

One limitation of the DFE score measurement as described above is that it fails to give any information about the extent of innovation with regard to a product's design, its packaging or its production processes. Did the IC EcoDesign project lead to a major product redesign, to a minor product improvement, or to an improvement of the product's packaging or production processes? Or has the project failed to result (as yet) in any of these technical changes? The assumption is that the DFE result will be higher if the project has led to a major product redesign than if it has failed to lead to any concrete improvements at all. This aspect of DFE result is reflected by a third DFE result indicator, the so called DFE design impact. The measuring scale of the DFE design impact variable consists of ten categories; these are given in Figure 3.8.

DFE design impact	At the moment of interviewing the IC project had led to or improved ...
10	... the development of a product that was 'new to the world'
9	... the development of a product that was 'new to the company'
8	... a 'major product redesign'
7	... a 'minor product improvement'
6	... a 'packaging improvement'
5	... a 'production process improvement'
4	... DFE-oriented research (still under way)
3	... DFE-oriented research (completed)
2	... DFE-oriented research (planned)
1	... no concrete improvements or DFE-related research

Figure 3.8 *The scale for measuring the DFE design impact: the third DFE result indicator*

The reason for including the DFE design impact variable when measuring DFE result is to provide an indication of the innovational potential of the set of suggested DFE improvement options. The higher the innovational potential, the more valuable the IC EcoDesign project for the company. This approach resembles the approach taken by Van Berkel who compared the results of various cleaner production programmes. As one of the elements for evaluating a set of cleaner production options, he used a method to calculate the 'technical innovation' of a set of cleaner production options. This indicator was based on the 'waste causes' to be reduced by a cleaner production option and the 'technical features' of each option (Van Berkel, 1996:47). However, in this research into DFE performance, the technical impact or innovational potential of the DFE improvement options has not been identified for each option individually (on pragmatic grounds) but for each company's set of options as a whole.

DFE result opinion

The fourth aspect which is indicative of a high DFE result is whether the company's representative feels that the IC EcoDesign project has or has not led to concrete results. This variable is called 'DFE result opinion' because it reflects the company representative's views as to the concrete results achieved by the IC EcoDesign project. The representatives were asked to express their opinion about the project results on a scale of 1 (no concrete results) to 5 (high concrete results).

In conclusion, Figure 3.9 shows how the DFE result (as an element of DFE performance) is operationalized by means of four DFE result indicators: DFE score, DFE project score, DFE design impact and DFE result opinion.

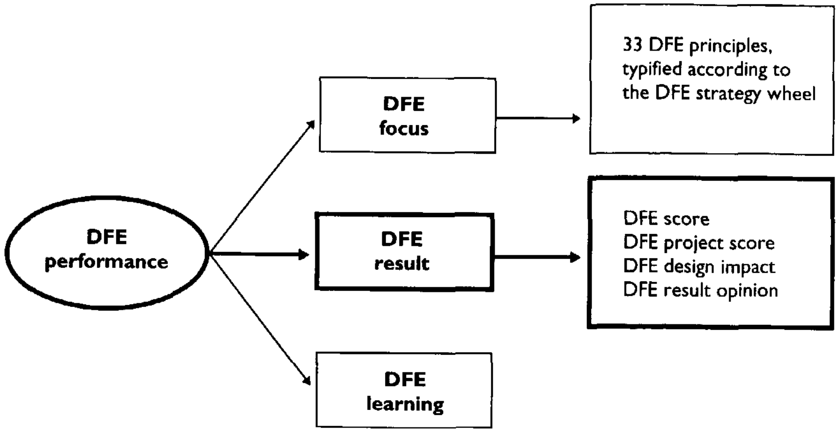


Figure 3.9 *Measuring DFE performance; how the second dependent variable, DFE result, is operationalized by means of four DFE result indicators*

3.4 How to measure DFE learning?

The outcome of an intervention project is not only reflected in the concrete environmental product improvements that have been achieved, but also in the learning effects as well. These learning effects are considered fundamental for the application of newly learned DFE principles in future product development projects. An explanation of how DFE learning is measured in this study is given below.

3.4.1 Measuring organizational learning

Den Hond (1996) performed a comparative study to assess and explain the differences in strategy followed by seven car manufacturers with respect to the recycling of their products. The aspect of organizational learning plays an important role in Den Hond's study. In it, he states that solving problems by creating or renewing capabilities for the purpose of closing the gap between a company's actual performance and the performance it would like to see is an innovative activity, in which organizational learning plays a major role (Den Hond, 1996:68). On the basis of an extensive literature review he goes on to state that the aspect of learning in the organization as such is achieved through the individual members; yet it surpasses the learning of individuals (Fiol and Lyles, 1985). It surpasses learning-by-doing and learning curves (Malerba, 1992). Codification and simplification of knowledge is needed to transfer knowledge to other members of the organization (Kogut and Zander, 1992). Other members of the organization, in order to learn from somebody who knows, have to integrate this knowledge with their own knowledge and skills (Nonaka, 1994). In a similar vein, Kogut and Zander (1992:384) speak of a 'combinative capability', both at the level of the individual and at the organizational level. It is in this sense that Nelson and Winter (1982) regard routine procedures as organizational memory. Organizational learning with regard to DFE will be referred to as the development of DFE learning. Following Nelson and Winter's line of thinking ***DFE learning*** in this thesis refers to those routines that enable and encourage the company to independently apply DFE in future product development projects.

The importance of organizational learning with respect to industrial environmental initiatives is also stressed by Roome (Roome 1992; Roome 1994). He suggests that the application of management techniques in concert with organizational learning and organizational change is needed for R&D management to effectively transform environmental considerations into innovation. Roome (1994) distinguishes three environmental strategies (compliance; compliance plus; excellence) and ranks the associated organizational change (first-order; second-order; third-order). Figure 3.10 illustrates

Roome's vision (1994) of the relation between the three environmental strategies and organizational change.

		Excellence	Compliance plus	Compliance
First order :	Techniques and greener technology	●	●	●
Second order:	Management systems and structures	●	●	
Third-order :	Organization and individual values/culture	●		

Figure 3.10 Environmental strategies and organizational change (Roome, 1994:73)

This vision is also addressed and supported by other authors (Milbraith, 1990; Steger et al., 1990; O'Riordan, 1991; Stead and Stead, 1992). While their statements seem very plausible, the methods they used are not backed up by empirical findings and are somewhat normative by nature. Because they lack a clear operationalization they offer only a limited amount of support in the efforts to find indicators for the operationalization of DFE learning for this study.

Van Berkel attempted to operationalize the 'long-term learning effects' indicator. These effects were the results of several cleaner production programmes (Van Berkel, 1996). He performed an international study on cleaner production in order to evaluate and compare the results of four cleaner production programmes. Van Berkel describes the long term results of a cleaner production project as 'creating the favorable conditions for sustaining and expanding the environmental improvements in the longer term'. To assess these long term effects he used two parameters: the 'technical impact' and the 'systemic impact' of the suggested set of improvement options. The 'systemic impact' parameter refers to the cleaner production related learning effects and is therefore similar to DFE learning.
Van Berkel states that the past evaluation studies of cleaner production demonstration projects tend to either neglect systemic changes as a success factor for cleaner production projects or use a haphazard inventory of organizational and systemic features for the purpose of assessing whether or not a company has made progress in integrating cleaner production into the daily operation and strategic development of the company (Van Berkel, 1996: 52).

Van Berkel used the results of two cleaner production evaluation studies (Bosveld et al., 1995; Van Berkel et al., 1993), plus two selected environmental management surveys (Dorfman et al., 1992; Dillon et al., 1992), to draft a set of nine management practices conducive to cleaner production, which in turn are said to constitute the basis for the systemic impact evaluation. These management practices are organized in an environmental management model system (adapted from Van der Kolk et al., 1992) at the policy level, the organization level and at the operational level (Van Berkel, 1996:55). This model is illustrated in Figure 3.11.

Policy	1. Environmental Policy 2. Environmental Goals 3. Production Management
Organizational	4. Leadership 5. Environmental Reporting & Communication 6. Employee Involvement
Operational	7. Cleaner Production Assessments 8. Materials Accounting 9. Cost Accounting

Figure 3.11 Environmental management practices conducive to sustainable cleaner production efforts (Van Berkel, 1996:55)

The first level covers 'company environmental policies'. The second level is the 'organizational' level and deals with leadership in cleaner production and the division and allocation of environmental tasks, duties and responsibilities. The third level is the 'operational' level, covering the instruments used for implementing the company's environmental policies. Van Berkel states that to safeguard the continued application of the cleaner production concept, completion of the assessment should result in systemic changes in other instruments as well as at the organizational and policy level. According to Van Berkel, these nine environmental management practices for cleaner production partially coincide with the practices listed in the newly developed ISO 14001 standard for environmental management systems. A reference description has been given for both a 'partial' and an 'advanced' development stage of each management practice. The systemic impact is then evaluated on the basis of the comparison between the development stage of all practices before and after the cleaner production assessment. This results in a 'low', 'significant' or 'high' systemic impact.

Van Berkel claims that the parameter for systemic impact (and also the other parameters that he developed to evaluate cleaner production programmes) has its value for the evaluation of a product-oriented environmental improvement project as well (Van Berkel, 1996: 67). His translation of the parameter 'systemic impact' for evaluation of a cleaner production programme to a parameter for systemic impact for evaluation of a product oriented environmental improvement project is given in Figure 3.12.

Systemic impact with respect to cleaner production	**Systemic impact with respect to DFE**
a. Policy: integration of environmental concerns in production management	a. Policy: integration of environmental concerns in product strategy
b. Organization: leadership by production management and staff and involvement of production organization	b. Organization: leadership by product development management and staff and involvement of product development organization
c. Operation: integration of environmental concerns in production reviews and accounting	c. Operation: integration of environmental concerns in design reviews, market research and marketing

Figure 3.12 Preliminary application of the parameter 'systemic impact' of the evaluation scheme to product oriented environmental improvement projects as suggested by Van Berkel (1996:67)

On the subject of DFE, Van Berkel suggests the systemic impact should be assessed according to the following topics:

- 'Policy', referring to a written statement drawn up by the company's top managers as to their commitment to DFE and the setting up of long-term goals for DFE in product planning;
- 'Organization', referring to the assignment of responsibilities for DFE to product development managers and staff; furthermore, employees should be encouraged to become involved in DFE (by training and by prompting and rewarding DFE ideas);
- 'Operation', referring to the incorporation of environmental concerns in standard operating procedures, applied during product development.

3.4.2 Measuring DFE learning

The operationalization of the dependent variable DFE learning, as a result of the IC EcoDesign project, is related to the model described above. Three levels of organizational learning for measuring a company's DFE learning, as suggested by Van Berkel, are applied in this study. Van Hemel operationalized the parameters for systemic impact (as set out in Figure 3.12) as indicators for DFE learning. The resulting nine indicators for measuring a company's DFE learning are listed in Figure 3.13.

Levels	Environmental management practices	Indicators for DFE learning
Policy level	Integration of environmental concerns in product strategy	DFE policy DFE objectives DFE Management System integration
Organizational level	Leadership by product development managers and staff, and the involvement of product development organization	DFE internal involvement DFE external involvement
Operational level	Integration of environmental concerns in design reviews, market research and marketing	DFE awareness DFE follow-up activities DFE specification DFE protocol

Figure 3.13 *Nine indicators for measuring DFE learning, related to the Environmental Management Practices suggested by Van Berkel (1996:67)*

In the study reported on in this thesis, the nine indicators reflecting DFE learning were measured by using a comprehensive set of variables, listed in Figure 3.14 below.

	Indicator of DFE learning	Variables
Policy level	1. DFE Policy	• Communication of DFE activities in the company's annual report • Communication of DFE activities in the company's corporate journal • Communication of DFE activities in other corporate publications
	2. DFE Objectives	• Environmental concerns in product planning procedures • Environmental concerns in specifications of products • DFE dedicated budget when budgeting product development projects • Marketing the DFE activities or improved environmental product profile
	3. DFE Management System Integration	• Assignment of DFE responsibilities to employees • Incorporation of DFE in the company's Quality System • Incorporation of DFE in the company's Environmental Management System
Organizational level	4. DFE Internal involvement	• Number of employees participating in the IC Ecodesign Project • Internal communication on the IC Ecodesign Project (8 variables)
	5. DFE External involvement	• Cooperation on DFE within the supply chain (vertical) • Cooperation on DFE within the industry (horizontal) • Cooperation on DFE with knowledge institutes • Discussion of DFE issues with customers • Discussion of DFE issues with recyclers/disposers
Operational level	6. DFE Awareness	• Knowledge on DFE in general • Knowledge on environmental aspects of the materials used by the company • Knowledge on the environmental profile throughout the product's life cycle • Knowledge on product-oriented environmental legislation/regulation • Being prepared for the forthcoming take-back legislation • Being able to apply DFE independently in future product development
	7. DFE Follow-Up Activities	• Execution of feasibility study of the suggested DFE improvement options • Cost accounting of the suggested DFE improvement options • Application of DFE to other products (2 variables) • Search for DFE-related information after the intervention • Application of DFE-related software after the intervention • Participation in DFE meetings after the intervention • Participation in DFE training after the intervention • Other DFE-related follow-up activities
	8. DFE Specification	• Specification of DFE concerns in procurement procedures • Specification of DFE concerns when outsourcing production activities • Specification of DFE concerns when outsourcing development activities • Specification of DFE concerns in quotations drawn up for customers
	9. DFE Protocol	• Requires suppliers to sign a non-toxicity declaration • Requires suppliers to sign a take-back obligation • Development of a company-specific DFE manual • Development of a company-specific DFE checklist

Figure 3.14 *The variables that operationalize the nine indicators of DFE learning*

The companies participated in the IC EcoDesign project in 1995; the data in this study was generated about eighteen months later. This meant that it was impossible to take zero measurements to estimate the DFE learning in the companies before intervention took place in the form of the EcoDesign project. A zero measurement would have resulted in more reliable conclusions as to the actual influence of the IC EcoDesign project on the companies' DFE learning.
We may assume that if a company achieved a high DFE result and a high level of DFE learning, the project had either initiated or enhanced a process of change in the direction of DFE. Nevertheless, the predictive value of the DFE result and DFE learning indicators is still limited. We must admit that there is no guarantee that a company with a high level of DFE learning will achieve 'sustainable development' in 10 years' time.

In conclusion, Figure 3.15 presents an overview of the indicators used to measure the three dependent variables DFE focus, DFE result and DFE learning. These three variables are quantitatively and qualitatively indicative of the DFE performance in the small and medium-sized enterprises that participated in the IC EcoDesign project.

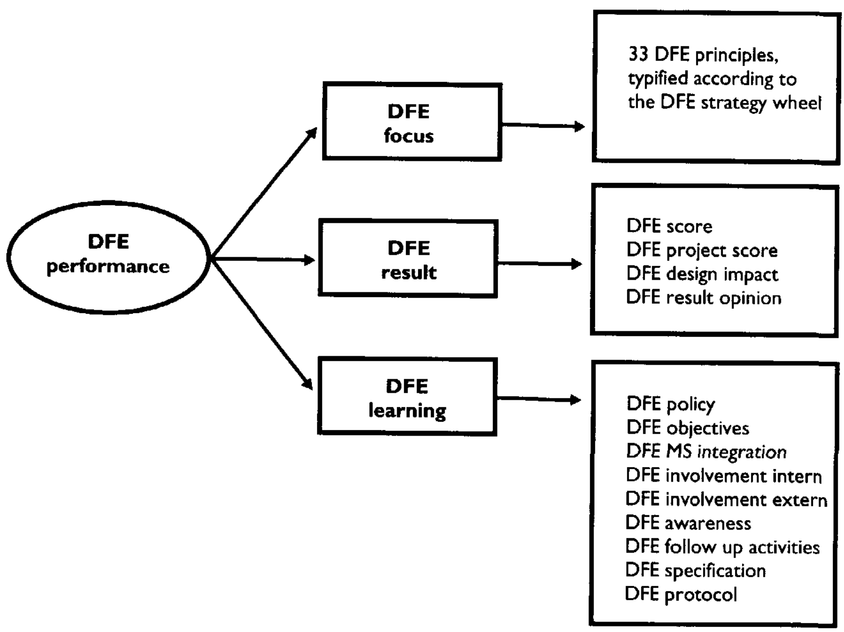


Figure 3.15 *Measuring DFE performance; operationalization of the third dependent DFE performance indicator (DFE learning)*

4. Design for environment in small and medium-sized enterprises

This chapter reports the results of a theoretical analysis aimed at gaining insight into the factors that either motivate or demotivate industrial companies to apply design for environment and to learn more about those features which are characteristics of pro-active companies in this field. These two central research questions are refined and transformed into research model A with hypothesis 1 and research model B with hypotheses 2 to 6.

4.1 Stimuli and barriers for design for environment in small companies

4.1.1 Introduction

If we take a close look at the DFE strategy wheel introduced in Chapter 2, we see that a company can follow as many as 33 different directions the moment it decides to apply DFE. These are typified as 33 DFE principles with a total of eight DFE strategies. Based on past experiences with DFE (e.g. Van der Horst and Te Riele, 1994) the assumption is that not all DFE principles are equally successful; some DFE principles will have a higher chance of being realized than others. Research question A is whether we can explain this expected variation in degree of success of these various DFE principles.

The approach chosen to answer this question was to identify the stimuli and barriers regarding the implementation of DFE improvement options perceived by the SMEs participating in the IC EcoDesign project. To this end, current environmental management theory was explored with the aim of finding out which factors influence a company's awareness and activities with regard to environmental management in general. This was then taken as input for the pre-structured questionnaire used during interviews by telephone.

Figure 4.1 illustrates the aforementioned research focus A. This figure shows the relation between specific stimuli and barriers for a certain DFE principle and its success rate. The question mark symbolizes the aim of research focus A: to learn more about the relationship between the stimuli and barriers for each DFE principle (as perceived by the SMEs) and the success rate of that specific DFE principle. In the following, this relation is elaborated upon for both large and small enterprises by means of the existing theory on stimuli and barriers in the field of environmental management in general and DFE in particular. This eventually leads to the identification of three groups of stimuli and barriers, as well as to the elaboration of research focus A into research model A with the hypotheses 1.A, 1.B and 1.C.

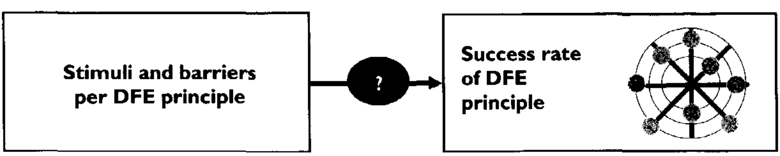


Figure 4.1 *Research focus A: Measuring, comparing and explaining the assumed variance in the success rate of the 33 DFE principles typified in the DFE strategy wheel*

In this thesis DFE is seen as a specific type of industrial environmental initiative. The term 'environmental initiative' is used to encompass all the potential activities pursued by a company aiming for reducing the environmental impact of its activities: environmental management systems (EMS), cleaning technology, cleaner technology, as well as DFE. We need not start from the very beginning to learn about stimuli and barriers for DFE as a specific type of industrial environmental initiative. Empirical research with regard to the implementation of EMS and cleaner technology has already been conducted, offering us some preliminary insight into the factors that stimulate companies to integrate environmental issues in their business (Green et al., 1994; De Groene en Hafkamp, 1994; Carter et al., 1995; Groen, 1995; De Groene, 1995; Van Berkel, 1996; Smith et al., 1996; Dewberry, 1996). We can even profit from some empirical, though scarce, research in this area focusing on smaller companies (Patton et al., 1994; Winter and Ledgerwood, 1994; Hutchinson and Chaston, 1994; O'Laoire and Welford, 1995; Hutchinson and Hutchinson, 1995; Rowe and Hollingsworth, 1996).

The initial focus below is on the stimuli that can influence initiatives in the field of cleaning technology and EMS, particularly by larger companies. The focus then shifts towards literature on the environmental behaviour of small and medium-sized enterprises. Only in the next part, Section 4.1.4, do we focus on literature on DFE.

4.1.2 Stimuli for environmental management

Authors analyzing corporate environmental management have identified a similar trend. In the past, only government environmental regulations have exerted an influence on industrial practice. Nowadays, there is a larger number of players who pass on the environmental message to industrial companies. De Groene and Hafkamp (1994) and Van Someren et al. (1993) for instance mention the following players:

- the consumer, who is said to be more and more environmentally concerned;
- suppliers who, because of the financial disadvantages involved, do not wish to see their products end up in a commodity which is environmentally suspect;
- retailers, who become key-players between the producer and the consumer;
- financial organizations, like banks and insurance companies, that are beginning to understand that environmental problems should be seen in the same light as financial risks or opportunities;
- relevant industrial organizations that start to make heavier environmental demands on their members;
- employees, who do not wish to be associated with a company that does not care about the environment, and who have first-hand experience of the environmental problems caused by their company and therefore feel responsible;
- local residents who also have first-hand experience the environmental problems of the industrial activity in their residence area and who refuse to accept dust, smell or noise any longer;
- and last but not least, (inter)national legislative bodies that stimulate companies to identify, measure, report and reduce environmental problems related to their industrial practice by means of legislation, regulation and liability claims.

Besides external stimuli factors like the ones mentioned above, internal stimuli also play a role (RMNO, 1989; EIM, 1995; Van der Woerd et al., 1990; De Vries and Altenburg, 1995; De Groene, 1995). Generally speaking, ***external stimuli*** include those players who, from outside the company, influence the attitude towards the environment within the company. ***Internal stimuli*** are those stimulating factors that originate inside the company itself. Internal stimuli originate more directly from environmental commitment and the wish to maintain or enhance commercial values and competitive advantages, like cost reduction, increased efficiency, image improvement and employee motivation.

We must acknowledge the fact that a stimulus can sometimes be interpreted as an external, as well as an internal stimulus. This is the case for instance if a company is motivated to improve its environmental image after discovering that most of its competitors have a better environmental image. The external stimulus is thus formed by the activity of competitors; the result is an internal stimulus to improve the company's own environmental image. However, in this theses this stimulus is seen as an external one, since its origins are external (the competitors' activities). It would, however, be interpreted as an internal stimulus if the company wished to improve its environmental image, not in response to the activities of its competitors, but with the aim to stay ahead of its competitors and to achieve a competitive advantage. The problem of how to distinguish external from internal stimuli is also addressed in literature on organization and innovation where there is no focus on environmental issues (Stacey, 1993; Dankbaar, 1996). For example, Dankbaar distinguishes a 'reactive system' and a 'creative, entrepreneurial system' with respect to product innovation. In order to activate the reactive system it is essential that signals come in from the outside world; it is driven by external stimuli. On the other hand the creative entrepreneurial system needs no external stimuli; it generates impulses in the direction of the outside world in order to change it. This system is driven by internal stimuli. Dankbaar states that although the two systems can be distinguished, they should not be regarded as separable. He makes reference to a 'transition zone' in which the two systems interact; external stimuli can then be interpreted as internal stimuli and vice versa.

One example of empirical environmental management research that addresses both external and internal stimuli is reported by De Groene (1996). She performed a comparative study among ten Dutch companies that were either developing or already had an EMS in place. While the focus of her study was EMS, the issue of cleaner technology (plus DFE, which De Groene also regards as one of the elements of cleaner technology) was also mentioned. Various branches of industry were included: the food industry, the printing trade, the paint industry, building materials, metal products and garages. These companies ranged in size from 25 to 1600 employees. She measured the external factors that influenced their environmental activities and how they responded to these external factors.
Based on the classifications of Van der Woerd et al. (1990) and EIM (1995) De Groene distinguished external factors (government, customers, local residents, relevant industrial organizations, competitors, suppliers, environmental consultants in the relevant branch of industry and the trade unions), internal factors (cost reduction, image improvement, integration of care systems, risk management and competitive advantage) as well as personal factors (personal environmental commitment). The stimuli distinguished by De Groene are set out in Figure 4.2; while De Groene regarded 'concern commitment' as an external factor this issue is still listed in Figure 4.2 as an internal factor because the stimulus originates from within the company. Moreover, the 'respondent's commitment' stimulus is also regarded as an internal factor. The factors in Figure 4.2 which have been placed in brackets were mentioned less often by the ten companies studied than the others. Supported by the results of her study, De Groene concluded that the importance of external factors should not be overestimated. Internal factors play an important role as well. Eight of the ten companies studied claimed to be influenced in their attitude towards environmental management by both internal and external factors. Half of the companies studied said they practiced environmental management because of their environmental commitment. Based on her findings, De Groene stated that the manager's personal commitment (the respondent in her research) was a major factor in this respect.

Van Someren et al. (1993) and Carter et al. (1995) reported on other relevant empirical studies into factors which influence the implementation of cleaning technology and EMS in businesses. The aim of the study carried out by Van Someren et al. (1993) was to survey the extent to which Dutch companies had introduced concrete measures to reduce their environmental impact, and how much progress they had made in establishing an environmental management system. The focus was on measures for good housekeeping, cleaning technology and environmental management systems. The empirical data for the study had been gathered in 1992 by means of 1,002 telephone interviews with companies and institutes that were causing a medium to high environmental load. This had been preceded by a pre-test in 1991. All the companies had at least 20 employees and a total of seven industries were represented: chemical industry, food industry, metal industry, building industry, other branches of industry, the service industry and government institutes. Data derived from case studies carried out in 55 companies and telephone interviews with 60 intermediary organizations (mainly industrial organizations) were subsequently added to the data that had already been gathered. The stimuli for EMS and cleaning technology identified by Van Someren are (1993:b.29) set out in Figure 4.2; the number after each stimulus indicates the number of times it was mentioned by the 55 companies.

Carter et al. (1995) reported the results of a research project carried out to identify the external influences that affect participation in environmental audit programmes and the internal factors that could stimulate or change the response to these influences. The focus of this study was on good housekeeping, cleaning technology and EMS. The companies that had been selected for the study were all in the manufacturing or supply sector and all were potential polluters. The report failed to state company size; since Carter had made an analysis in which the 'mean reported preparedness score' is analyzed as a function of company size (measured in total number of employees) we may assume that the companies varied from small to large. A questionnaire was sent to the person responsible for environmental/safety matters in 100 companies and was returned by 48 companies (response rate 48%). It requested information on the company itself, the beliefs and experiences of the respondents, the factors that had influenced the company, and how the company had reacted to them. The stimuli found by Carter et al. are also listed in Figure 4.2; the percentages given after the stimuli indicate how many of the 47 companies studied mentioned that specific stimulus for environmental management.

The analysis of literature on encouraging environmental management resulted in an overview of external and internal stimuli (presented in Figure 4.2). This table should be interpreted as being indicative rather than exhaustive. Neither Van Someren et al. nor Carter et al. distinguished external from internal stimuli explicitly. However, in order to facilitate comparison, the implicit distinction is made explicit in Figure 4.2.

	Environmental initiatives (focus on EMS / cleaning technology)		
	Van Someren et al. (1993) 55 companies	Carter et al. (1995) 48 companies	De Groene (1995) 10 companies
External stimuli	Governmental demands, 35[1)] Pending sanctions/claims, 10 Govt., stimulating projects, 5	Impending legislation, 82% [2)] Existing legislation, 80% Environm. inspections, 49%	Government [3)]
	Customer demands, 11	Customer demands, 42%	Customers
	Articles in media, 2	Fear of bad publicity, 42%	Local residents
		Pressure group activity, 9%	
	Results environmental audit, 9	Environmental consultants, 2%	Envir. consultants of sector
	Industrial sector, 9 Covenants, 6	Trade association, 2%	Industrial sector (Trade union)
	Competitors, 1		(Competitors)
			(Suppliers)
Internal stimuli	Higher efficiency short term, 5 Higher efficiency long term, 17	Cost savings, 49%	Cost reduction
	Competitive advantage, 7 Image improvement, 22 Environment is 'profit centre', 4		(Competitive advantage) Image improvement
	Synergy with quality system, 28 Synergy with Occupational Health & Safety, 25		Integration with care systems
	Commitment higher educated employees, 5	Management commitment, 2%	(Concern commitment)
	Commitment respondent, 24 Discussions with colleagues, 3 Training / conference, 3	Employee commitment, 8% Work force commitment, 4%	Respondent's commitment
	Environmental pollution, 12 Reduction of risks, 13	Crisis incidents, 2%	(Risk management)

1) The number indicates the number of times the 55 companies studied mentioned the specific stimulus
2) The percentages indicate what percentage of the 48 companies studied mentioned the specific stimulus
3) The stimuli in brackets were mentioned less often by the 10 companies studied than those not in brackets

Figure 4.2 External and internal stimuli for implementing an environmental management system (EMS) and cleaning technology, derived from literature

The stimuli listed in Figure 4.2 were based on analyses of companies that were known to have a medium to high environmental impact. All the companies included in the study ranged from being reactive to pro-active. The respondents in all three studies were persons responsible for environmental affairs; in the smaller companies this was usually the owner/manager. We must acknowledge that their answers might have been biased because of personal interest. We should also be discriminating in how we interpret the importance of a certain stimulus, based on the figures given in Figure 4.2; the number of companies referring to a certain stimulus is simply a general indication.

Comparing the empirical data set out in Figure 4.2 we may conclude that the most frequently mentioned external stimuli are actual and pending governmental regulation, customer demands and media attention (fear of bad publicity/pressure group activities). The external stimuli mentioned less often are the influence of environmental consultants and industrial organizations. External stimuli hardly mentioned at all are developments from the side of competitors and suppliers. The latter is hardly surprising since implementation of an EMS or cleaning technologies is regarded as an internal matter and not a marketing tool. This could change if a company's EMS can be certified on the basis of international ISO 14000 standards for environmental management, or in the event a company adopts a more product-oriented approach.

The most often mentioned internal stimuli are cost savings (through a higher level of efficiency), image improvement, the respondents' environmental commitment, and synergy with care systems. This corresponds with the increasing amount of attention given to quality/ occupational health and safety, as reported by Dietz (1994) and RMNO (1989). One less often mentioned, yet relevant internal stimulus is the aim to reduce the element of risk. This corresponds with the increasing amount of fear of liability claims, as reported by De Bruijn et al. (1992). Internal stimuli mentioned hardly at all are competitive advantage and corporate commitment ('commitment of higher educated employees' by Van Someren et al.; 'management commitment' by Carter et al.; 'concern commitment' by De Groene). This emphasizes yet again that implementing an EMS or cleaning technologies is not seen as a marketing tool. Moreover, the respondents in all three studies stated that they had not experienced much support for environmental management from their top management.

4.1.3 Stimuli for environmental management in small companies

The literature referred to in the section above dealt with empirical research in large companies. However, various other authors stressed that smaller companies differ substantially in many respects from their larger counterparts (Rice, 1983; Dilts and Prough, 1989; EIM, 1995). This means that, without further consideration, we may not simply assume that any conclusions drawn for large companies are also valid for SMEs. Therefore this section discusses to what extent the stimuli we found for large companies are relevant for their smaller counterparts as well.

Various empirical studies demonstrate that the *types* of external stimuli for environmental management in large businesses do correspond to types of external stimuli in small companies. One example is Winter and Ledgerwood's study (1994) whose empirical findings show that the main driving force for environmental management in small companies is legislation and regulation. Other driving forces are consumers, investors (private and institutional), industrial customers, pressure groups and employees. All of these (with the exception of the company's employees) are regarded as external stimuli.
Groen (1995) performed an empirical study on environmental management in the printing trade, focusing on SMEs. He concluded that the dominant stimuli for environmental management in this sector were: government regulations, changes in municipal authority requirements for the granting of environmental permits, plus the fact that companies' had to make capital investments anyway (in machines or building), paving the way to integrating environmental demands (1995: 136).
A study by EIM (1995) again stressed the impact government regulations had on the introduction of environmental management in SMEs. In addition to the aspect of regulation the study also identified pressure from customers, suppliers and investors as external stimuli for environmental management. Internal stimuli are the company's awareness of the environmental impact of its activities, the corporate commitment towards environmental management, and the possible financial benefits involved. Relevant in this context is the conclusion drawn by Hutchinson and Hutchinson (1995) that government regulation is the most significant driving force for environmental management, both in small and larger companies.

Although the ***types*** of stimuli for environmental management are similar if we compare larger and smaller companies, it is still assumed that their ***relative importance*** differs significantly. The actual impact of government regulations seems to weigh less heavily for SMEs than for large companies (De Bruijn et al., 1992). The first reason De Bruijn gives for this is that small companies are generally less well-informed about government regulations. Moreover, up to the present day environmental legislation has concentrated on the larger companies, sometimes causing confusion in small companies. This finding is confirmed by Dogson and Rothwell (1994) who state that smaller companies only tend to react to legislation some time after it has been formalized. Contradicting the findings of Hutchinson and Hutchinson, Rowe and Hollingsworth (1996) found that the key incentives for small companies to improve their environmental performance were cost reduction, customer demand and, to

a much lesser extent, environmental legislation. Again, this assumes while pressure from environmental legislation is theoretically relevant for small companies, in practice it is still a relatively 'weak' driver.
Since the resources of small companies are usually more limited than those of their larger counterparts, they are strongly dependent on investors like banks and insurance companies. We may assume that the pressure exerted by investors regarding environmental issues is taken seriously by small companies. This is confirmed by empirical research carried out by Hutchinson and Hutchinson (1995) who found that one-third of the SMEs studied stated that environmental management was stimulated by pressure from banks and insurance companies.
As far as pressure exerted by customers is concerned, Hutchinson and Hutchinson (1995) found that small companies feel the need to comply with the existing industrial standards put forward by their customers, and thus prevent themselves from being excluded from the market. External stimulus for environmental management in the form of 'customer demands' is therefore assumed to be relevant for both large *and* small companies.

We may assume that (theoretically) the types of external stimuli for environmental management for small companies are more or less similar to those that apply to the larger companies. However, small companies usually only have a modest impact on the environment when compared with larger companies. The resulting external pressure from government, customers, suppliers, investors, etc., is therefore assumed to have at least some relevance for SMEs.
In this thesis the internal stimuli brought about by environmental commitment or anticipated commercial benefits are thought to play a more important role than the external stimuli. Given that this study assumes that internal stimuli play an important role in improving the environmental management in SMEs, they will be discussed in detail below.

On the basis of empirical research, Winter and Ledgerwood (1994) conclude that most small companies tend to see 'the environment' as a threat - because of the associated legislation and perceived costs - more than larger companies. SMEs are less likely than larger companies to believe in the concept of 'pollution prevention pays'.
Hutchinson and Chaston (1994) concluded that smaller companies work more ad-hoc and with short-term objectives than larger companies that apply strategic management and set longer-term goals. In other words, smaller companies will not easily become enthusiastic about the possible long-term commercial benefits of environmental management. We may assume that small companies attach less importance to this internal stimulus than large companies.

Hutchinson and Hutchinson (1995) concluded that the higher level of efficiency brought about by environmental management is perceived as a relevant internal stimulus by small companies. However, because the organizational structure of small companies and their production processes are usually less complex than those of larger companies (EIM, 1995), we may assume that small companies do not regard a potential increase in efficiency as such an important internal stimulus for environmental management as their larger counterparts.

Improving the corporate environmental image by installing a certified environmental management system (EMS) only provides a weak internal stimulus towards environmental management for large companies. They may benefit from a certified EMS (on the basis of certification systems BS 7750, EMAS or ISO 14000) given that it underscores their credibility and quality image towards customers. Nevertheless, an EMS is sometimes only a cosmetic initiative, used as a company 'green-wash' (Lang and Hines, 1993). Smaller companies in particular are unhappy with these developments. Clunies-Ross and Hildyard (1992) explain the reactive response of small companies to environmental protection measures by their suspicion that environmental regulation can be manipulated by large companies to erode the market share of small companies. As a result, what is an internal stimulus for environmental management in large companies becomes a barrier for small companies. Therefore we may expect that small companies will not regard implementation of an EMS as a suitable marketing tool.

A commitment to reduce the environmental impact can be a strong internal stimulus to introduce environmental management in SMEs. Various authors claim that owner-managers in small companies usually have a very strong influence (EIM, 1995). Therefore, the personal commitment of a small company's management (often just one person: the owner-manager) towards environmental issues can be a very significant internal stimulus: he is the person who either rejects or aims to reduce the company's environmental impact. We suspect that if the owner-manager has a strong environmental commitment, it will lead to a relatively high level of environmental concern in the company as a whole. In practice, however, the owner-managers of small companies' are usually overloaded with responsibilities, constantly lack time and are not particularly eager to create formal structures unless they are absolutely necessary (De Bruijn et al., 1992). These factors might reduce the resulting impact of the internal stimulus *'environmental commitment'*.

To conclude this part on internal stimuli for environmental management we assume that the commercial benefits of environmental management are perceived as being much less important by small companies than their larger counterparts. The predominant stimulus towards environmental management seems to be the personal environmental commitment of the company's owner-manager, as opposed to the potential commercial benefits in the sense of cost reduction, cost anticipation, increased efficiency or image improvement. We therefore suspect that the strongest internal stimulus towards environmental management for small companies is the owner-manager's personal commitment towards reducing his company's environmental load, plus a similar commitment on the part of his employees.

4.1.4 Stimuli for design for environment

So far the focus has been on factors that stimulate environmental management in companies in the sense of environmental management systems and cleaning technology. However, it is also interesting to find out whether the factors that stimulate companies to introduce environmental management are the same as those that encourage companies to undertake cleaner production and (where our main interest lies) design for environment.

Relevant empirical research on this subject is reported by Green et al. (1994) presenting the results of a 1993 survey of UK companies on the impact of 'green' pressures on the innovative directions that companies pursue, both in the sense of innovation of production processes (cleaner technology) and innovation of products (design for environment). Because the work of Green et al. does not focus on cleaning technology and EMS but on green process and product innovation in particular, their findings are described in detail below.

The main purpose of this survey was to identify those factors that stimulated companies to innovate more environment-friendly products and processes, and to investigate the changes in R&D activity they had undertaken to facilitate such innovation. The research was set in the context of the 'technological trajectory/selection environment' framework, as developed by Nelson and Winter (1977) and interpreted by Dosi et al. (1982). In this context of 'evolutionary economics' it is usual to distinguish only external factors, factors that are perceived as features of companies' selection environments. Green et al. notice however that, in addition to external factors, studying internal stimuli is crucial as well to obtain an understanding of environmental innovations within companies.

The questionnaire was sent to 800 companies selected from a list of companies which had expressed an interest in the Environmental Technology Innovation Scheme of the UK Department of Trade and Industry. This scheme supports industrial R&D projects for innovations that might 'pave the way for improved environmental standards' in both products and processes. The questionnaires were addressed to the person responsible for environmentally-related R&D or innovation. This was usually the R&D director or senior environmental executive in the larger companies or the managing director in the smaller companies. It was returned by 169 companies (a response rate in the region of 20%), representative of small, medium-sized and large companies as well as all manufacturing (and some service) industries.

Figure 4.3 lists some of the research results in the fields of cleaner technology (or to quote Green et al.: green process innovation) and design for environment (Green et al. use the term: green product innovation), based on the average ratings of 125 companies. The number after the factor indicates its importance, rated by the respondents on a scale of 1 (not important) to 5 (very important).

	Green *process* innovation	**Green *product* innovation**
	Green et al. (1994) 125 companies	Green et al. (1994) 125 companies
External stimuli	Existing regulations, 3.90[1)] Anticipated regulations, 3.74	Existing regulations, 3.81[1)] Anticipated regulations, 3.69
	Retailer/wholesaler pressure, 2.59	Retailer / wholesaler pressure, 3.12
	Rival green processes appearing, 2.00 Rival green processes feared, 1,96	Rival green products appearing, 2.47 Rival green products feared, 2.38
	Availability of new technologies, 3.05 Change in supplied components, 2.24	Availability of new technologies, 2.97 Change in supplied components, 2.10
	Environmental campaigns, 1.99	Environmental campaigns, 1.85
	Insurance cost pressures, 2.05 Ethical investment pressures, 1.98	Insurance cost pressures, 1.97 Ethical investment pressures, 2.01
Internal stimuli	Cost savings materials / energy, 3.56	Cost savings materials / energy, N/A.
	Prospect of expanding market share, 2.56	Prospect of expanding market share, 3.36
	Change in HQ company policy, 2.52	Change in HQ company policy, 2.25
	Commitment of employees, 3.09	Commitment of employees, 3.02

1) The number indicates the importance of the stimulus, rated by the respondents on a scale of 1 (not important) to 5 (very important)

Figure 4.3 *External and internal stimuli for green process and product innovation, as reported by Green et al. (1994)*

First of all we compare the stimuli for process innovation given by Green et al. (Figure 4.3) with the stimuli for EMS and cleaning technologies listed in Figure 4.2. The stimuli for green process innovation and for green product innovation, both mentioned by Green, will be compared at a later stage.

The top three factors found by Green et al. (1994) for process innovations were the existence of environmentally-related regulations, the anticipation of environmentally-related regulations and cost savings achieved through better use of materials/energy. This is similar to the top three stimuli for EMS and cleaning technologies found by Carter et al. (1995) and reflected by Van Someren et al. (1993) and De Groene (1995) (see Figure 4.2).
If we compare Figure 4.2 and Figure 4.3 we see that the external stimulus exerted by suppliers (the availability of new technologies) seems to be more important for green process innovation than it is for EMS and cleaning technology. Also, the internal stimulus of 'employee commitment' seems to be more important for green process innovation than for EMS. However, the figure Green et al. give could reflect the respondent's own environmental commitment, which was an important stimulus for EMS as well.
The two external stimuli 'fear for negative media attention' and 'customer demands' (retail/wholesale pressure) seem to be less important in the case of green process innovation than for EMS and cleaning technology (listed in Figure 4.2).
The internal stimuli of 'competitive advantage' (prospect of expanding market share) and 'corporate commitment' are not very important, neither for EMS nor for green process innovation. As is the case for environmental management too (in the sense of EMS and cleaning technology), activities pursued by competitors are not relevant with regard to green process innovation.
The influence of environmental consultants, the company's industrial organizations and the aim to reduce risks, were not mentioned in Green's research findings. In case of EMS and cleaning technology they were mentioned, but not very often. Nevertheless, we may assume that governmental or industrial organizations aiming to raise the level of environmental awareness and improve industrial activities have a certain amount of influence on corporate environmental initiatives. Also, the factors of 'image improvement' and 'synergy with quality and Occupational Health & Safety systems' (which were important internal stimuli for environmental management) are not included in Green's study.

In conclusion we may assume that the types of internal and external stimuli for green process innovation correspond to those for environmental management in the sense of EMS and cleaning technology. This is hardly surprising since the main intention of these environmental initiatives is to comply with legislation and government regulations, and to secure the actual market shares. Neither EMS nor cleaning or cleaner technology aims to achieve new product development or product modification. They are focused on the activities within the company itself and do not interfere with the other partners in the product supply chain. As mentioned by Cramer (1994) in this sense, the two fields of environmental interest show some degree of overlap and are not always clearly separable.

For product innovations (see Figure 4.3) the first and second of the top three factors (actual and pending legislation) are similar to those for process innovations and environmental management. The third most important factor was not cost reduction however, but the prospect of expanding one's market share with new, 'green' products. This immediately emphasizes the difference in commercial value of design for environment (green product innovation) on the one hand and green process innovation, cleaning technology and EMS on the other: contrary to EMS and cleaner technology, competitive advantage can be seen as a strong internal impetus towards design for environment.
Other interesting differences between the stimuli for green product innovation and green process innovation are the following. First, we see that the external stimulus of 'customer demands' (retail/wholesaler demands) is much more important with regard to green product innovation than to green process innovation. This can be explained by the fact that the environmental aspects of products for the industrial or consumer market are more obvious than those of the company's production processes for example.
Second, the external stimulus of 'activities of competitors' (rival green products appearing/feared) becomes relevant, contrary to the issues of green process innovation and EMS. Again, this may be due to the fact that environmental *product* improvements are more obvious and easier to communicate than environmental *process* improvements, not only in the direction of the market but also to the industrial sector, including the company's competitors.
While there are no weighing factors to assess the importance of 'cost reduction' we may assume that it is an important internal stimulus for all three fields of environmental business considerations.

Carter et al. (1995) concluded that companies pursue those strategies in environmental management that will lead to environmental as well as commercial benefits. This statement highlights the importance of the identification of internal stimuli for environmental management in the sense that internal stimuli are mostly related to commercial values. This is supported by the findings of Smith, Roy and Potter (1996) who analyzed sixteen British, American and Australian companies which had deliberately or incidentally introduced significant environmental improvements to the design of their products. One of their findings was that most companies in their study did not set out to produce a 'greener' product. Instead they aimed to develop a product that would perform better, create a new market, increase or maintain market share, or satisfy market demands or regulatory pressures. Often it was only a secondary result that the companies recognized the environmental advantages of their new or improved product. Environmental factors were thus taken into account in pursuit of commercial aims (1996: 3).

In Figure 4.4 the findings about stimuli for environmental management, green process development and green product development are combined. The column 'EMS/cleaning technology' is derived from Figure 4.2; the columns 'green process innovations' and 'green product innovation' are both derived from Figure 4.3.

		EMS / cleaning technology	**green process innovation**	**green product innovation**
		Figure 4.2	Figure 4.3	Figure 4.3
External stimuli	Government regulation	●●	●●	●●
	Customer demands	●	○	●
	Fear of negative media attention	●	○	○
	Environmental consultants	○	?	?
	Industrial sector	○	?	?
	Competitors' activities	--	--	○
	Suppliers' activities	--	○	○
Internal stimuli	Cost savings	●	●	●
	Image improvement	●	?	?
	Synergy with care systems	●	?	?
	Respondent commitment	●	○	○
	Corporate commitment	○	○	○
	Competitive advantage	○	○	●
	Risk reduction	○	?	?

●● : very important stimulus
● : important stimulus
○: relevant, but not very important stimulus
-- : no relevant factor
? : relevancy not reported

Figure 4.4 Comparison of the stimuli for environmental management, green process development and green product development, derived from Figure 4.2 and Figure 4.3

The findings presented in Figure 4.4 lead to the assumption that there is one main difference between the stimuli for EMS, cleaning technology and cleaner technology and those for DFE: DFE seems to have a higher potential to result in synergy with commercial values than the other issues in the field of environmental management. The reason for this seems to be that environmental management is associated with implementation and certification of an environmental management system that records and controls the environmental impact of a company's activities; the commercial benefits can be cost reduction, increase in efficiency and, to a certain extent, image improvement. The key-word in environmental management is 'control'.
Design for environment, however, seems to be of a different nature: it has the potential to lead to product improvement and even new product development, together with possible commercial benefits like cost reduction, increased efficiency, increased product quality and functionality as well as the possibility to increase market share or access to new markets. The key-word in design for environment is 'development'.
In contrast, cleaner technology, as another type of environmental initiative, seems to be somewhere between 'control' and 'development'. Whether the highest achievable environmental benefit can be reached by green process innovations (cleaner technology) or by green product innovations (design for environment) depends on the type of company - manufacturers of raw materials or intermediate products or those that manufacture end-products. However, our focus is on companies that manufacture end-products and not on the process industry.

Nevertheless, the claim that DFE always results in 'win-win' situations is not justified. Whether a win-win situation occurs depends on a wide range of different factors. One of these is a company's innovation capacity (RMNO, 1989). A win-win situation occurs when a company sees DFE as an opportunity and manages to turn it into a green product innovation. Another factor is the timing of introducing the 'greener' product on the market: the expectation is that companies that take the lead will be able to benefit from the advantage they have above their followers and exploit the commercial value of their improved product to a large extent (Krozer, 1992). Companies that follow the trend, improving their products only at a later stage in order to keep up with their competitors' greener products, miss out on the opportunity to exploit the commercial benefits of their own environmentally improved products. This development is expected to only occur in a politically stable situation and if environmental standards remain unchanged; pro-active companies can otherwise be trapped in their own pro-activity.

.1.5 Stimuli for design for environment in small companies

So far, the discussion about the differences between the stimuli for small and large companies was restricted to the area of environmental management in the sense of implementing EMS and cleaning technology. The motivation for environmental management in larger companies was assumed to be based on a mix of external and internal stimuli; for large businesses with a reactive attitude external stimuli are expected to be more influential than internal stimuli. The conclusion was drawn that small companies that have adopted a policy of environmental management are motivated mainly by internal stimuli (because external stimuli for SMEs are scarce), of which the 'personal commitment of the company's management' is assumed to be dominant. The question that must then be asked is whether we may assume that SMEs are motivated mainly by internal stimuli in the area of DFE too, predominated in this case by the internal stimulus 'personal commitment of the company's management'. We assume that this is indeed the case on the basis of the following arguments.

The preceding section concluded that DFE would generally seem to have more potential to lead to synergy with commercial values, than the other environmental management issues. Internal stimuli, and in particular the stimulus of 'synergy with commercial values', are expected to be more important in the case of DFE than in case of the other environmental management issues.
If we assume that internal stimuli are the ones that generally motivate SMEs to introduce environmental management (as stated above), *and* that all companies are influenced more by internal stimuli regarding DFE than the other environmental management issues, we may expect that (for DFE) SMEs will be influenced more by internal than by external stimuli.

What then is the most influential internal stimulus for SMEs with respect to DFE, 'synergy with commercial values' or the 'personal environmental commitment of the SME's owner-manager'? On the basis of conclusions drawn by Schot (1995) we assume that, in case of SMEs, 'personal environmental commitment' is a much stronger driving force for DFE than 'synergy with commercial values'. Schot (1995) is one of the few authors who report empirical research on the subject of green product and process innovation in small companies. The dominant stimuli for DFE in SMEs identified by Schot were the wish to keep up the company's credibility and government regulation (1995: 207). These stimuli perceived by small companies with regard to DFE reflect an attitude towards DFE which is more reactive than that of larger companies; the SMEs studied seem to believe less strongly than large companies that DFE can result in synergy with commercial benefits. According to Schot, the internal stimulus 'expected synergy with commercial values' has less influence on small companies than the other stimuli for DFE.

This can be explained partly as follows. To identify the potential commercial benefits of DFE it is essential that companies assess its potential future impact. Small companies seem to be less equipped for strategic decision-making than larger companies; in general, they tend not to look as far ahead into the future as their larger counterparts. They also have less capital to invest in new (green) product development (EIM, 1995; Hutchinson and Chaston, 1994). However, we should be wary of making generalizations: we can expect to find some positive exceptions of SMEs that do hold a highly innovative attitude with respect to DFE. As argued by Smith et al. (1996), should they decide to change existing R&D, sales and production procedures, SMEs are able to reap the rewards of smallness of scale simply because they are more flexible than larger companies.

Summarizing the above arguments, we may conclude that in 1996 SMEs do not seem to experience a great deal of external stimulation for DFE apart from government regulation. Since there are very few product-oriented environmental regulations as yet that apply to small companies, we assume that within these small companies the internal stimuli will dominate. The internal DFE stimulus of 'expected synergy with commercial values' seems to be less influential for small companies, and we therefore expect that in case of SMEs the internal stimulus of 'personal commitment to decrease environmental impact' will be dominant above all other internal and external stimuli. These two assumptions lead to the following hypotheses, 1.A and 1.B, to be tested in the research:

Hypothesis 1.A: Regarding the application of DFE in SMEs, the actual influence of internal stimuli on the success rate of DFE principles is stronger than the influence of external stimuli.

Hypothesis 1.B: Of all the internal stimuli that motivate an SME to implement DFE options, the personal environmental commitment of that SME's owner-manager is the most influencing factor.

We have distinguished a set of external and internal stimuli based on the literature mentioned above. These could explain why the participants in the IC EcoDesign project tend to implement certain DFE improvement options suggested in the DFE action plan, and reject others. This helps us to create a picture of why certain DFE principles are more successful than others. These external stimuli correspond to a large extent to those set out in Figure 4.4. The internal stimuli are derived from those given in Figure 4.4 as well. However, certain alterations have been made.

The internal stimulus of 'environmental commitment' is often broken down into various items in the literature: commitment of the respondent, that of top management and of the employees.
In this research the respondent was asked to state whether he or she thought the aim to improve the environmental product profile was an important stimulus. If the answer was 'yes' then it reflected his or her environmental commitment. Since the focus was on small companies, the respondent is usually the manager-owner, therefore the respondent's commitment is assumed to reflect top management commitment as well.
The internal stimulus of 'competitive advantage' is broken down into two separate stimuli: 'image improvement' and 'new market opportunities'. The internal stimuli of 'increase of functional product quality' and 'synergy with product requirements other than quality or costs' have been distinguished separately to identify the actual benefit of the DFE improvement option more clearly. Another internal stimulus has been added, that of 'interesting long-term innovation opportunities'; this is a stimulus we had been unable to find in literature. This particular stimulus reflects a strategic interest to invest in the new technology or development since it is thought that it will become a potentially important innovation opportunity in the future.
The stimuli for DFE as used in this study are summarized in the tables of Figure 4.5 (external stimuli) and Figure 4.6 (internal stimuli).

External stimuli (direct influence of external parties, their attitude and/or activities):

1. The option is subject to legislation and government regulations, actual or pending;
2. The option is subject to environmental pressure from industrial organizations;
3. The option is subject to the environmental demands of customers at the consumer, industrial or institutional market;
4. The option is subject to negative media attention caused by environmental action groups;
5. Suppliers offer newly developed eco-efficient materials or components related to the specific option;
6. Competitors have already applied the specific DFE option to their products;
7. Another external stimulus is perceived for the option.

Figure 4.5 External stimuli for DFE, used in assessing motivation to either realize or reject the company's suggested DFE improvement options

Internal stimuli (reasons why DFE is interesting, regardless of the influence of external parties):

1. The company expects a reduction of the environmental impact (commitment to reduce the environmental impact);
2. The company expects a reduction of costs (lower cost-price of the product);
3. The company expects an image improvement (leading to competitive advantage);
4. The company expects new market opportunities (competitive advantage: increasing actual market share/access to new markets);
5. The company expects an increase of the product's functional quality;
6. The company expects a synergy with product requirements other than functional quality demands or low costs;
7. The company expects a commercial benefit, other than those mentioned in 2, 3, 4, 5 or 6 (e.g. synergy with care systems, risk reduction, increased efficiency in production, storage, distribution, etc.);
8. The company regards the option as an interesting long-term innovation opportunity;
9. The company perceives another internal stimulus.

Figure 4.6 Internal stimuli for DFE, used in assessing motivation to either realize or reject the company's suggested DFE improvement options

4.1.6 Barriers standing in the way of environmental management and DFE

So far we have focused on those factors that stimulate environmental management and design for environment. In our search to explain why certain DFE principles are more successful than others we expect a DFE improvement option to be stimulated by strong external or internal drivers, yet sometimes they are still not implemented. Certain barriers, consciously or unconsciously, may form an obstacle that impedes the suggested option from being realized. It is therefore important then to focus on the barriers as well. We may assume that one of the main barriers for environmental management in general, and for DFE in particular, arises if a company fails to experience any external or internal stimuli. Yet even if a company experiences stimuli, there may still be certain barriers that counteract these stimuli, resulting in action not being taken in the field of DFE.

The empirical studies of Van Someren et al. (1993) and Carter et al. (1995) looked at the barriers that stop companies from pursuing a policy of environmental management, focusing on the implementation of environmental management systems and cleaning technology. Van Someren et al. (1993:b.27) suggest that the most important barriers standing in the way of environmental management are the lack of time and capacity, uncertainty as to how government regulation will evolve, insufficient in-company commitment, implementation can only be achieved step by step ('it needs its time'), plus the fact that many companies are not sure what their environmental responsibilities are.
The dominant environmental management barriers in the empirical study of Carter et al. (1995) were related to the perceived costs, to the 'non-fit' in terms of corporate culture and to the lack of awareness. According to Carter, apart from developing consistent regulations, the importance of cost and culture suggests that financial assistance and training will also be useful policies to encourage environmental management.
Cramer and Schot (1990) identified a set of six obstacles that stand in the way of the development and diffusion of cleaner technology in particular. Crul (1994) identified seven types of obstacles, particularly in the field of DFE, based on an analysis of the results of the first Dutch EcoDesign project 1991-1993. The aim of his study was to gain an insight into the barriers that prevent companies from pursuing a policy of DFE and that also form obstacles to realizing the environmental improvement options suggested during the project. The companies involved were medium to large companies, representing various industries.

The barriers or obstacles identified for EMS and cleaning technology, cleaner technology and DFE respectively are summarized in Figure 4.7. The table shown in this figure distinguishes between external barriers (barriers originating outside the company) and internal barriers (independent of external factors).

	EMS / cleaning technology		cleaner technology	design for environment
	Van Someren et al. (1993) [1)]	Carter et al. (1995)	Cramer and Schot (1990)	Crul (1994)
External barriers	Uncertain future regulation, 21 Ill-defined responsibility, 14 Uncertainty as to how the severity of env. problems will be perceived in the future, 12 Unclear decision making, 13 Unclear demands for EMS[2)], 14			Uncertainty as to government regulations
	No customer interest, 10		No structural demand	Uncertainty about market reaction
			No proper knowledge infrastructure	Lack of standardized method / data base for env. analysis
				Lack of organization / cooperation in supply chain
Internal barriers		Costs Too high investment	Uncertainty about financial risks	No overview of costs / benefits
	Lack of time / capacity, 30			
	Lack of environmental knowledge, 14	Lack of awareness Skill shortage	Lack of expertise / know-how	Lack of sufficient environmental know-how
	Lack of management commitment, 12 Lack of employee commitment , 14 Lack of middle management commitment, 15	Attitude / cultural barriers Lack of priorities Short-term outlook Feeling that 'enough has been done'	Lack of innovative commitment	Lack of management commitment Conceptual (prejudiced attitude: 'DFE limits design freedom') Resistance to change product design (conflicting demands)
	Implementation can only be achieved step by step, 16 No clear division of in-company responsibilities, 13 No structural approach, 11		Social / organizational adjustment problems in the company	Lack of proper internal organization
				Conflicting product demands (environm. vs. quality / safety)

1) The figures indicate the number of times the factor was mentioned by the 55 companies studied ; only those barriers mentioned more than 10 times are listed

Figure 4.7 *Comparison of external and internal barriers of EMS and cleaning technology, cleaner technology and DFE*

As also was the case with regard to external and internal stimuli for environmental management and design for environment, here too must we be careful when comparing the findings in literature. First, the number of times barriers are mentioned is often no more than an indication of their relative importance. Second, the barriers that exist for pro-active companies might be entirely different from those perceived by reactive companies. The barriers mentioned above came from companies in which the attitude ranges from pro-active to reactive; no clear distinction can be made. These barriers therefore only give us a rough idea as to the general barriers perceived by industrial companies.

Research shows that similar environmental management barriers exist in both small and large companies. Exemplary in this respect is the research performed by Carter et al. (1995) who pointed out that dominant barriers for environmental management are the expected costs and non-fit in corporate culture (1995: 92). They stated that this conclusion also counts for small companies since it is supported by the findings of Patton et al. (1994) and Hutchinson and Chaston (1994), whose empirical studies focused on the small company sector as well.
Based upon interviews with small companies, Winter and Ledgerwood (1994) conclude that the constraints that operate to counter environmental activity can be classified in three categories: ignorance (low awareness), reluctance (low priority, lack of commitment), and inability (lack of time, energy, relevant expertise and funding). He expected that these environmental management barriers would be relevant for small as well as large companies. However, 'inability' and 'ignorance' are expected to be stronger barriers in small companies than in larger businesses.

O'Laiore and Welford (1995) found that small companies often claim that their environmental initiatives depend on the initiatives of their larger counterparts in their branch of industry. They feel less equipped and less able to concretize their environmental concerns than their 'big brothers'. Because smaller companies have a relatively small environmental impact, they may be inclined to play down and sometimes even deny the company's environmental impact and their responsibility or decisional power to realize environmental improvements.

In an empirical research carried out by Hutchinson and Hutchinson (1995) small companies which applied no form of environmental management whatever were asked to motivate this. The barriers they mentioned, in order of descending importance were:

- the existing environmental efforts are satisfying;
- we do not have enough time;
- our environmental impact is low, therefore environmental management is not relevant;
- we don't have sufficient finances;
- there is no reason to apply environmental management;
- we don't have sufficient know-how or environmental information;
- we can't estimate our future environmental impact.

Apart from those relating to lack of time, finances and know-how ('inability'), all the barriers mentioned above emphasize that the small companies studied do not feel responsible for reducing the environmental impact of their activities ('ignorance' or 'reluctance'). This is supported by the empirical research findings of Rowe and Hollingsworth (1996). More than half of the small companies they studied in Avon (UK) thought that they had no or minimal environmental impact. This corresponds to the results of the Groundwork survey (Groundwork, 1995) which revealed that 58% of the small companies studied felt they had a 'quite' or 'very' low environmental impact. We may conclude that the combined environmental impact of all small companies is generally not perceived as a problem by the individual companies. It is not clear whether this is due to 'ignorance' or 'reluctance'.

The barriers mentioned above relate mainly to environmental management, focusing on the implementation of EMS and cleaning technology. Based on Figure 4.7 we expect that these barriers will usually stand in the way of cleaner technology and design for environment as well. This is confirmed by the findings of Schot (1995), who performed empirical research on green process innovations as well as on product innovations in both large and small companies. Schot suggests that the dominant barriers for green product development for smaller companies were the anticipated R&D costs of new developments, uncertainty as to how the market would react, the limited marketing/sales facilities of smaller companies, and the risk of an innovation being quickly copied by larger companies (1995: 177).

A comparison of the research findings on design for environment barriers in small companies versus larger companies, leads to the assumption that the kind of barrier does not differ all that much. However, the barriers do seem to have a greater influence on small companies than large ones. Small companies in general feel less responsible for the environmental impact of their products than larger companies because of their comparatively small, individual environmental impact and their limited resources for product development.

A set of barriers for DFE was developed in this study on the basis of Figure 4.7, to be used in evaluating why certain DFE principles are more successful than others. This set of barriers is presented in Figure 4.8 below.

Some of the barriers found in literature relate to the implementation of DFE in general and not to a certain DFE option type in particular. These 'general' DFE barriers do not explain why a certain DFE principle is very successful in comparison with others: they have a low explanatory value. As an example of this we mention a set of 'bottlenecks to environmentally oriented product development in companies' as listed by Hanssen (1997). These bottlenecks were identified during a workshop in 1994 with 26 participants (environmental experts and representatives of large companies) which started the 'Nordic Project on Environmentally Sound Product Development' (NEP project). The most important bottlenecks mentioned were the lack of participation of environmental experts in the product development process, lack of methods for environmentally-oriented design, lack of environmental data and the lack of experience in companies in integrating life cycle assessment (LCA) in product development. Because barriers like these are generic and have a limited explanatory value, they were not included in this study.

We see that some barriers relate to external stimuli and others to internal stimuli. However, because we have not studied the effects of the external versus the internal barriers (as we did in case of the stimuli for DFE) the distinction between external and internal barriers is discontinued.

Operationalization of barriers standing in the way of the suggested DFE improvement options:

1. Doubt in respect of the environmental benefit of the option suggested;
2. The company does not feel responsible for realizing the option:
3. The option only becomes relevant if supported by environmental legislation;
4. The option only becomes relevant if supported by market demands;
5. The option creates a commercial disadvantage for our company;
6. The option creates a conflict in connection with actual functional product requirements;
7. The option is not a challenging technological innovation opportunity for our company;
8. Realization depends on available technical possibilities; at the moment there is no proper alternative;
9. The company regards new investments in redesigning the product in question as fruitless;
10. The company lack sufficient time to realize the option in question;
11. The company lacks sufficient knowledge to realize the option in question;
12. The company perceives another type of barrier.

Figure 4.8 *DFE barriers, used in assessing motivation to either realize or reject the company's suggested DFE improvement options*

According to Winter and Ledgerwood (1994) barriers 1 to 7 in Figure 4.8 can be characterized as 'reluctance' and barriers 8, 9, 10 and 11 as 'inability'. The third topic, that of 'ignorance', is not applicable since the company was acquainted with all the DFE improvement options.
The barriers 'lack of management commitment' and 'conceptual barriers', discussed in literature, are specified here as barriers 1, 2, 3 and 4. Uncertainty about future environmental legislation is translated as barrier 3: this option only becomes relevant if it is supported by environmental legislation. Uncertainty about how the market will react is translated into barrier 4: this option only becomes relevant if it is supported by market demands. The barriers of 'no overview of costs/benefits' and 'conflicting product demands' are operationalized by barriers 5, 6 and 7.

A comparison of the external and internal stimuli for DFE referred to in Section 4.1.4 and those mentioned above reveals certain similarities. However, it would be incorrect to claim that each stimulus can be translated into a barrier or vice versa. For example, a lack of capacity may be an enormous barrier for a company to realize certain DFE improvement options. However, if that company had surplus capacity it would still not create a stimulus towards DFE: such a barrier cannot simply be turned into a stimulus. Nevertheless, in some cases there is a close link between stimuli and barriers, as will become clear in the following.

Some stimuli are thought to be so important that their absence could result in a barrier. In such a case, a barrier is included in the set of barriers listed above. This can occur with the external stimuli 'government regulation' and 'customer demand'. Literature has shown that these stimuli have a strong influence on industry's environmental attitudes and activities. The stimulus 'government regulation' is related to barrier 3. The stimulus 'customer demand' is related to barrier 4. The other external stimuli have less influence; their absence will not lead to barriers.
The relationship between internal stimuli and barriers is slightly more complex. As was the case with external stimuli, some internal stimuli are also thought to have such a strong influence that their absence could result in a barrier. This applies with regard to the internal stimuli 'reduction of environmental impact/environmental commitment' and 'interesting long-term innovation opportunities'. The assumption is that the absence of these stimuli can lead to a barrier. The stimulus

'reduction of environmental impact/environmental commitment' is related to barrier 1; the stimulus 'interesting long-term innovation opportunities' to barrier 7.

Also some other internal stimuli are related to barriers, but in a different sense. These stimuli are influential, but their absence does not create a barrier. However, such a stimulus can be converted into a barrier if a company perceives the 'opposite' of the stimulus. An example is the internal stimulus 'cost reduction'. The absence of this stimulus will not result in a serious barrier, since the DFE improvement option may lead to other interesting commercial benefits. However, if the issue 'costs' is influenced negatively ('converted'), meaning that the costs increase, this may lead to a serious barrier. This effect concerns the internal stimuli 'cost reduction', 'image improvement', 'new market opportunities' and 'other commercial advantage' that are all related to barrier 5; it also concerns the internal stimuli 'increase of functional product quality' and 'synergy with other product requirements', both related to barrier 6.

The barriers 2, 8, 9, 10 and 11 form a separate category of barriers: they are assumed to be very influential obstacles in the sense that if such a barrier is mentioned, the DFE improvement option has only a minor chance to be realized. Translating them into stimuli is however meaningless: a company may feel very responsible for realization of the specific option, there may be many alternatives available, the company may have redundant resources, time or knowledge at its disposal, but none of these factors is assumed to individually act as a serious driving force towards DFE.

The barriers listed in Figure 4.8 are used as input for the questionnaire used to assess the motivation behind the realization or rejection of certain suggested DFE improvement options.

.1.7 Stimuli and barriers for individual DFE principles

The preceding sections showed that empirical research has been carried out to identify the stimuli and barriers in the field of environmental management and (to a lesser extent) the field of design for environment. The stimuli and barriers thus identified might help us explain why companies apply DFE to a differing extent. However, the current theory is still unable to explain why certain DFE principles are more successful than others.

The only research that has addressed the question why companies prioritize certain DFE principles and reject others was performed by Den Hond. He sought to explain the variance in recycling strategies pursued by the various companies in the car industry (Den Hond, 1996).
Den Hond applied the capability theory to explain why companies (which were subjected to more or less the same external pressure) developed different approaches to recycling. He concluded that stimuli for companies to pursue recycling strategies in general were: the perception of a high environmental risk, the management's strategic vision, the desire to improve the corporate image, the aim to achieve relation management, the market opportunities and government regulations.
Based on the capability theory, Den Hond also stated that a company would prioritize recycling options that meet the following three 'requirements':

- ***Complementarity***: the option must be synergetic with existing or planned company activities;
- ***Technological options***: there must be sufficient technological options available to realize the option (the technology must be sufficiently developed), or the company must feel that the technology required to realize the option is so interesting (in terms of future innovation) that it wishes to invest in developing that technology;
- ***Appropriability***: the option must lead to a commercial benefit, that the company can appropriate so it results in a competitive advantage.

The aim of this study performed by Den Hond was to explain the different corporate attitudes concerning the DFE principle of recycling; not why the companies studied were heading in the direction of recycling and not other DFE strategies (e.g. energy control). However, we may assume that the three requirements mentioned above are not only relevant in the field of recycling, but for other strategies in the field of DFE as well.
Therefore, these three requirements will be used in this study to give some focus while assessing the influence of the barriers standing in the way of DFE. All three topics are regarded as prerequisites for

prioritizing the DFE improvement options. If any one of these prerequisites is not met, the result is a dominant barrier to implementing the DFE improvement option. However, if all three prerequisites are met it is still no guarantee that the DFE improvement option will be realized: there may be other barriers, like the absence of a strong internal or external stimulus.

The relationship between Den Hond's prerequisites and the barriers set out in Figure 4.8 is as follows:
- Not meeting the first prerequisite of *complementarity* corresponds to barrier 6: *The option creates a conflict with actual functional product requirements;*
- The second prerequisite, *interesting technological options,* is reflected in barrier 8: *Realization depends on the available technical possibilities* and 7: *The option is not a challenging technological innovation opportunity for our company.*
- The third prerequisite, *appropriability,* is reflected in barrier 5: *The option creates a commercial disadvantage for our company.* If the option creates a commercial disadvantage it will definitely not result in a commercial benefit; the DFE improvement option will be rejected.

The line of reasoning developed by Den Hond has also been used in this research to obtain a better insight into the reasons why companies prioritize certain DFE principles and reject others. The absence of systematic research on what motivates companies to give preference to certain DFE principles above others only gives greater relevance to the foremost focus of this research and results in augmenting hypothesis 1 with hypothesis 1.C.

Hypothesis 1.C ***The participants in the IC EcoDesign project will reject DFE improvement options that are susceptible to the barriers 'insufficient complementarity', 'lack of interesting technological options' or 'insufficient appropriability'***

4.1.8 Research model A

As a conclusion, the resulting research model A with the hypotheses 1.A, 1.B and 1.C combined into hypothesis 1 is illustrated in Figure 4.9.

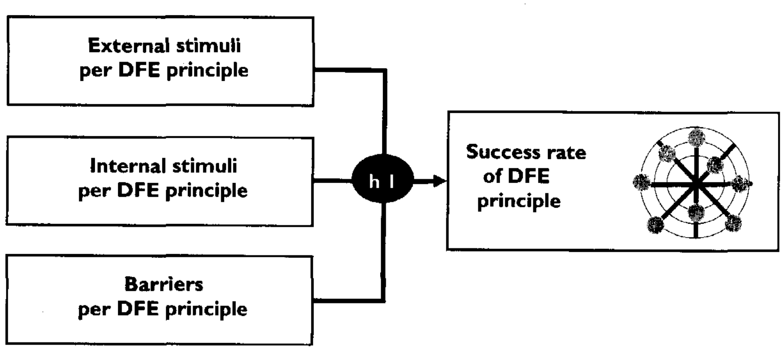


Figure 4.9 *Research model A with hypothesis 1, consisting of sub-hypotheses 1.A, 1.B and 1.C*

4.2 Corporate characteristics explaining DFE performance

4.2.1 Introduction

The second aim of this study is to explain why companies differ in terms of DFE performance as a result of the IC EcoDesign project. Literature about industrial environmental initiatives reports several initial research initiatives, explaining that certain companies are more active in the field of environmental management than others. Various conceptual models have been suggested to typify the attitude or stage of progress of companies in the field of environmental management (for overviews see Hass, 1994 and Mauser, 1996). However, this literature offers no empirically derived explanations as to why some companies are more successful in environmental management or what it is that distinguishes the pro-active companies in this field.

There are a few exceptions. For instance: an assessment of whether certain company characteristics predict a pro-active corporate environmental attitude and activities was made in the research carried out by Van Someren et al. (1993) on the stage of implementation of environmental management systems in Dutch companies (both small and large). The two characteristics selected for that research were company size and industrial branch. The conclusion was that large companies are generally more active than small companies in environmental management. This conclusion is not always supported by the findings of other studies. The study performed by Carter et al. (1995) for instance indicated that a company's size bears no relation to its environmental performance. Moreover, other literature contradicts the findings of Van Someren et al., expecting small companies (if run by managers with a strong environmental commitment) to show a higher performance than larger companies (Smith et al., 1996). In short, there is little empirically-based insight into (or indeed agreement on) what distinguishes environmentally pro-active companies.

The IC EcoDesign project offered the opportunity to study the DFE performance of a group of 77 small industrial companies (ranging from 3 to 200 employees). This DFE performance results from the application of a standardized DFE consulting method by Innovation Centre consultants with a similar DFE training. Although these companies represented a variety of industrial sectors, the project offered a setting to measure and compare the DFE performance of small companies on the one hand and, on the other hand, to measure a selection of corporate characteristics that can offer a partial explanation for the expected variance in DFE performance. The opportunity to obtain empirical data about the relationship between corporate characteristics and DFE performance of companies supported research focus B, the second aim of the research: learning why certain companies manifest a higher DFE performance than others.

What can existing theory teach us about the characteristics that explain the DFE performance of SMEs? Very little; there is a scarcity of literature on how to explain the variances in corporate DFE performance. In the initial stage of this study there was no well-defined theory that could serve as a theoretical basis to explain the differences in DFE performance among SMEs. This study therefore took an exploratory approach: instead of choosing for a narrow, strongly focused set of variables, we chose for a wide range of potential explanatory variables.

The traditional approach taken in empirical research on environmental management in industry is to focus on two company characteristics: company size and the branch of industry to which the company belongs. The setting of this research, however, offered the opportunity to go into greater detail, implying that a broader range of explanatory variables could be measured. The next four sections present the explanatory variables that were applied. In order to present an intelligible overview, the range of the variables selected was clustered into four groups:

- Company characteristics (culture and organization);
- Characteristics of the product selected;
- Characteristics of the company's representative (the respondent); and
- Characteristics of the IC EcoDesign intervention.

Research focus B, to identify and explain the variance in DFE performance among SMEs' on the basis of these four sets of explanatory variables, is illustrated in Figure 4.10.

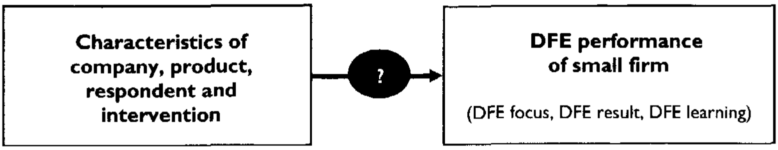


Figure 4.10 *Research focus B: Identifying and explaining the variance in DFE performance among the SMEs studied*

Chapter 3 explained how DFE performance, the dependent variable of research model B, is operationalized in this study. There are three indicators of DFE performance: DFE focus, DFE result and DFE learning. So far, we have assumed a high degree of correlation between these three indicators. Companies with a good DFE result are expected to have achieved a high level of DFE learning as well. Moreover, they are also expected to have a comparable DFE focus. The correctness of these assumptions must be tested before we can establish a link between a company's characteristics and its DFE performance. To do this, hypothesis 2 was constructed as follows:

Hypothesis 2.A: Companies that manifest a good DFE result, as a result of the IC EcoDesign project, will also achieve a high level of DFE learning.

Hypothesis 2.B: Companies that manifest a good DFE result and a high level of DFE learning as a result of the IC EcoDesign project also have a comparable DFE focus.

On the basis of literature on environmental and innovation management (which we shall discuss in detail in the following sections) the explanatory variables offered an initial point of departure for assessing the relationship between the characteristics and DFE performance of small companies. The following four sections discuss the four groups of characteristics, and their operationalization into explanatory variables.

4.2.2 Company characteristics and DFE performance

Since 1990 a considerable number of articles and books has been written world-wide on the subject of environmental management in industrial companies. This subject also deals with the need to study the organizational and cultural characteristics of companies that are actually managing to deal with the environmental aspects of their business and thus improve environmental management.
For instance: Green et al. (1994) concluded that it is impossible to predict whether a company will become active in the environmental field or not simply by looking at the external pressures exerted on a company. They state (1994: 1057-1058): "a spur for one company may be a threat to another - equally, it can be completely ignored. The key point here becomes the strategies, industrial cultures and organizational structures through which fresh challenges are constructed and acted on. Without that identification of a new innovatory climate, the 'greening of industry' will never take place". Worded differently, Winter and Ledgerwood (1994) say exactly the same, stating that corporate culture, managerial values and a company's response to environmental issues are intricately interlinked.

The traditional approach taken in empirical research to explain the differences in corporate environmental initiatives focuses on organizational characteristics like company size and relevant branch of industry (or more specifically, the amount of environmental pollution due to the companies' industrial activities). However, the conclusions found in the scarce literature on empirical research are sometimes contradictory: company size for example. Carter et al. (1995) found no link between the size of a company and its environmental initiatives. On the other hand, Rosa and Scott (1994), when assessing the awareness and preparedness of SMEs across Europe for the Single European Market, found that the general awareness of environmental legislation among SMEs was significantly correlated with the size of the company. If a company employed fewer than 51 employees, awareness was generally very low; full awareness was detected in companies employing more than 100 (Rowe and Hollingsworth, 1996). Hutchinson and Chaston (1994) found, on the basis of their study in the UK SME sector, that the larger the company, the more likely it would be to find environmental issues important. This could be due to various reasons, like larger companies having more time and money available to address environmental issues than their smaller counterparts, and consequently realizing the significance of the environmental debate. Or it could be due to a fear of adverse publicity that would more likely concern a larger organization. The main reason however is thought to be that the environment is ultimately a strategic issue that requires proactive planning to deal with it. The larger the company, the more likely the organization will have strategic management structures in place allowing for proactive environmental management to take place more easily (Hutchinson and Chaston, 1994).

In this study we have devoted attention to both organizational and cultural characteristics. Due to the inconsistencies found in environmental management literature, this study focuses on cultural characteristics, like the company's innovation potential and its environmental awareness, rather than on organizational characteristics, like a company's size and its branch of industry. While these two factors are included in the study, they have not been elaborated in a hypothesis.

The objectives of the IC EcoDesign project were to raise the level of awareness and increase activities in the field of ecodesign among SMEs. Design for environment or ecodesign differs quite clearly from the other industrial environmental initiatives in the sense that it combines *'eco'* (environmental issues) with *'design'* (product development). This leads us to assume that companies performing well regarding *eco* issues in general and/or other *design* or innovational issues, also perform well in the field of ecodesign. May we then conclude that companies with an innovative corporate culture are eco-innovative as well? And are industrial companies with a culture that shows a high level of environmental awareness, eco-innovative as well? Do companies with a positive attitude towards DFE yield good results in a project like the IC EcoDesign project? Since ecodesign is a relatively new subject of study we cannot yet answer this question.

In the past decades many words have been written on what characterizes 'the innovative company' (Cooper, 1985 and 1996; Chatman and Jehn, 1994; Mintzberg, 1988; Kleinknecht, 1987; Kleinknecht et al., 1992; Teece, 1988; Teece et al., 1994) in which the term 'innovative' refers to the *development* of innovations rather than the *implementation* of innovations. There are even some large scale empirical studies on the subject, like the projects NewProd (Cooper, 1980) and SAPPHO (Rothwell et al., 1974). Another interesting study about product innovation was conducted by Buijs (Buijs, 1984). In his research into the effectiveness of the intervention programme Pii-b (set up to increase the level of innovation in Dutch industry) Buijs expected that the 'quality' (in terms of a company's sales and profits at the moment of interviewing) of the participating companies would affect the result of the interventions (Buijs, 1984). This hypothesis could not however be empirically confirmed.

However, so far no empirical study has been made which assesses the relationship between innovativeness, the environmental awareness and the eco-innovativeness of industrial companies, let alone of SMEs. The urge to answer the questions asked above by means of empirical data resulted in the third set of hypotheses (3A, 3B and 3C) for this study, concerning the relationship between three cultural company characteristics and the company's performance in terms of DFE.
The assumption (to be supported or rejected by empirical evidence) is that SMEs with the cultural characteristics of a highly innovative potential, a high environmental awareness and a positive attitude towards DFE, perform better in terms of DFE than companies that lack such characteristics. This assumption is translated into hypothesis 3, which comprises three sub-hypotheses 3.A, 3.B and 3.C as presented below.
The operationalization and argumentation of the explanatory variables (called 'indicators') is set out after each of the sub-hypothesis. In addition to the three sub-hypotheses, the impact of a set of various company characteristics was also studied; this is explained after hypothesis 3.C.

Hypothesis 3.A *Companies with a high innovative potential have a higher DFE performance than less innovative companies.*

Innovativeness is measured according to the following indicators:

- A company that experiments, searches actively for new product ideas, spends a lot of resources on R&D, stimulates the creativity of its employees, takes risks, encourages its employees to take initiatives, is not a follower in the market, applies the newest technology and knows what the customers' wishes are, has an innovative attitude (based on Chatman and Jehn (1994) and Cooper (1996)).
- Products offering unique features are developed by innovative companies; products which have an outstanding quality come from innovative companies; products which are not me-too products come from innovative companies; if the cost price of a product is not too restricted the company can be more innovative; products which were new for the industry when launched, come from innovative companies; technically highly advanced products come from innovative companies.
- The companies' opinion: when a company thinks that it is more innovative than its competitors, it will have an innovative attitude.
- New product performance (percentage of sales by new products, based on Cooper 1985 and 1996). The percentage of the actual annual sales, thanks to the products the company has launched the last five years. A second indicator for new product performance is the percentage of the actual profit, thanks to the products the company has launched the last five years.

Hypothesis 3.B ***Companies with a high level of environmental awareness and activities have a higher DFE performance than companies with less environmental awareness and fewer activities.***

A company's environmental awareness is measured according to the following indicators:

- Presence of an Environmental Management System: Companies that have made their environmental awareness explicit in a (partial) EMS are more environmentally aware than companies without an EMS.
- Participation in the preceding IC project Cleaner Production: Companies that participated in the IC project Cleaner Production will be more environmentally aware.
- Environmental Covenant: Companies that signed an environmental covenant will be more environmentally aware than companies that did not.
- Perceived environmental awareness: Companies that claim to have undertaken more environmental activities than competitors are more environmentally aware.
- Environmental benchmarking: Companies that have executed one or more environmental benchmarks, comparing themselves with competitors on environmental issues, are environmentally aware.
- Explicit environmental responsibilities: Companies that have explicitly attributed environmental responsibilities to one or more company employees have a high level of environmental awareness.

Hypothesis 3.C ***Companies with a positive attitude towards DFE will manifest a higher DFE performance than companies with a critical attitude***

A company's DFE attitude is measured by means of the following variables:

- Experience with DFE before the Environmental Innovation Scan was performed: companies that have already introduced DFE will have a positive DFE attitude.
- The attitude of different company departments towards DFE: if management and the product development department, marketing/sales department, environmental affairs, quality assurance, purchasing and production departments all have an active DFE attitude, the company's DFE attitude is positive.
- DFE ambition: if the company's explicit ambition was to improve its product's eco-efficiency, it has a positive DFE attitude.
- DFE perception: if the company perceives DFE as an important aspect of product innovation, or a high level of eco-efficiency as an aspect of product quality, it has a positive DFE attitude.

Additionally studied company characteristics

Because the research setting offered the opportunity to measure organizational aspects as well, attention will also be given to the impact various organizational company characteristics have on DFE performance. Because the relationship between DFE performance and the characteristics set out below has been explored but not tested, the characteristics themselves have not been included in the research model. The additional company characteristics are:

- The number of employees: since larger companies have more capital to invest in DFE, plus the fact that they feel more environmentally responsible than smaller ones, it is assumed that the larger the company, the better the DFE performance.
- The branch of industry to which the company belongs: some branches of industry are more receptive for DFE than others and could therefore perform better in terms of DFE (based on Van Someren et al., 1993).
- The presence of an in-house product development department: better DFE performance can be expected if employees have a direct responsibility for product development.
- Freedom of specification, or the extent to which the company can draw up the specifications for its products 'autonomously': the more independently a company can draw up the specifications for its products, the better its DFE performance (based upon March, 1988).
- Place in the supply chain: companies which see product development as one of their core activities will manifest a better DFE performance than those focusing on other activities.
- The number of fixed procedures in product development: if a company has a well structured development process (check lists, milestones, design reviews) in place, it will probably perform better in terms of DFE than companies that organize their product development badly (based on Cooper, 1996).
- Product development tradition: companies that have a tradition in product development manifest a better DFE performance than those that have only just started to develop products. This is because it is far easier for a company with a well structured product development process to implement a new discipline like DFE.
- The presence of a Quality System: companies that already have a Quality System in place will have a better DFE performance since environmental quality can be regarded as an element of overall product quality.

4.2.3 Product characteristics and company DFE performance

Various empirical studies stress that external pressure is a prerequisite to motivate industry to incorporate environmental concern in their activities. We may therefore expect that companies under pressure from outside to introduce design for environment will yield better results than companies which feel no external pressure in terms of the environment at all. This leads to hypothesis 4.A.

Hypothesis 4.A *Products subjected to external pressure with regard to their eco-efficiency will prompt a higher DFE performance than those which are not.*

Whether the product is subjected to external pressure is measured by the following variables:

- Reason for selecting the product: if the reason was either current or pending environmental legislation the product is subject to external DFE pressure.
- Necessity of DFE: if environmental legislation makes DFE inevitable the product is subject to external DFE pressure.
- Reason for participation in the IC EcoDesign project: if the reason was the wish to be informed about environmental legislation, or because customers were requesting eco-efficient products, or because the product ran the risk of a negative environmental image, or because the company wanted to overtake its competitors in terms of the eco-efficiency of its products, then the product is subject to external DFE pressure.
- Environmental demands of customers: if a company had signed a non-toxicity declaration concerning its product, or if it has signed a take-back obligation for its products, the product is subject to external DFE pressure.
- Covenant at industrial branch level: if the branch of industry to which the company belongs has entered into an environmental covenant with the government, the product is subject to external DFE pressure.

- Environmental group action at industrial level: if the branch of industry to which the company belongs has ever been the target of environmental pressure group activities, the product is subject to environmental pressure.
- DFE attitude of external actors: if the attitude towards DFE in the branch of industry to which the company belongs, of the government, direct customers, product end-users, retailers/dealers, suppliers or competitors is very involved, the product is subject to external DFE pressure.
- DFE stimulation from external actors: if the company feels stimulated to introduce DFE by the branch of industry to which the company belongs, governmental regulation, direct customers, product end-users, retail/dealers, suppliers , competitors, consumer organizations or environmental pressure groups, then the product is subject to external DFE pressure.

The preceding section, Section 4.1, made it clear that the actual external stimuli towards DFE are not all that effective. Nevertheless, we expect to see significant differences in the DFE performance of the companies participating in the IC EcoDesign project. The assumption is that this variance is because of the amount of synergy with the existing business values, or commercial opportunities, resulting from DFE. This is the motivation for hypothesis 4.B.

Hypothesis 4.B *Products for which DFE offers commercial opportunities will lead to a higher DFE performance than those for which DFE is perceived as commercially neutral or negative.*

The commercial opportunities DFE offers to the product are measured by the following variables:

- The extent to which DFE is regarded as an opportunity for financial profit.
- The extent to which the company is able to use DFE as a marketing instrument and/or sales argument.
- The extent to which DFE is seen as an initial investment which will be profitable in due course.
- The extent to which DFE is seen as an investment for which there will be no pay off.
- The extent to which DFE is seen as a means of increasing the company's operational efficiency.
- The extent to which various costs are decreased by DFE: material and component purchasing costs, waste removal costs, production costs (including tool/machinery adjustment costs, costs incurred from testing, internal logistics, guarantee/repairs), packaging costs, transport costs, future take-back costs, R&D costs.
- The extent to which a rise in the number of sales is expected as a result of DFE: increase of market share in existing markets or the introduction of products on new markets.
- The total commercial benefit the company expects to achieve by introducing DFE.

Additionally studied product characteristics

Additional attention will be given to an exploratory study of the relation between DFE performance and the following product characteristics:

- The geographical market: products sold in the Netherlands and Germany are governed by a relatively large amount of environmental legislation and will therefore provoke a higher level of DFE performance than products sold in other countries (based on empirical research in the UK SME sector; Hutchinson and Chaston (1994) concluded that exporting SMEs found environmental issues to be significantly more important than non-exporters to their business practices. This, they reported, was probably due to the more stringent legislative requirements in the destination countries for the exporting companies, i.e. Europe and the USA).
- Product age: companies are less inclined to apply DFE to newly-launched products than to longer-standing products because they do not want to be faced with the need for re-investments in product development shortly after the product's launch.
- Product redesign frequency: products which tend to need redesigning frequently provoke better DFE performance than other products. If a product is frequently redesigned DFE improvement options can be realized in a relatively shorter period of time.
- Product life cycle stage: a product can be in the introductory stage, growth, maturity or decline stage of its (commercial) life cycle; when reaching the decline stage, products tend to trigger better

DFE performance because the company (and the branch of industry to which it belongs) then feels the urge to launch a new or redesigned product (based on Utterback and Abernathy, 1975).

- Functional life: if the product's function only lasts for a short period of time, like packaging, the product is prone to DFE because of the amount of waste it generates.
- Type of market : products meant for the industrial market (business to business) or governmental market trigger better DFE performance than products for the consumer market. This is because companies tend to take the environmental demands of industrial and governmental clients more seriously than those of general consumers.

4.2.4 Respondent characteristics and company DFE performance

Carter et al. (1995:93) are some of the many authors who stress the importance of the environmental commitment of individual workers to achieve a reduction in corporate environmental impact. He noted a tendency among companies to achieve better results if the respondents in his study were, or felt they were environmentally responsible for environmental auditing (1995:89).
According to Hutchinson and Chaston (1994) many writers have commented that senior level commitment to the environment is absolutely essential for a company to become more environmental friendly. In small companies, senior level management is often the only form of management in the company. For this reason alone, small companies should be easier to convert to the benefits of being environmentally friendly as their organizational structures are less complex and their business operations are more flexible (Hutchinson and Chaston, 1994: 20). Literature and manuals on environmental management and on design for environment constantly stress the necessity of top management commitment (Brezet et al., 1994).
We can therefore expect that if the owner/manager of a small company participating in the IC EcoDesign project has a strong environmental commitment, this will result in a high level of DFE performance. This motivates the following hypotheses, 5.A and 5.B.

Hypothesis 5.A *A high personal environmental commitment on the part of the company's representative contributes towards DFE performance.*

Personal environmental commitment is measured by:

- The extent to which the company's representative claims that his personal environmental commitment was a reason to participate in the IC EcoDesign project.

Hypothesis 5.B *If the company's representative has a positive attitude towards DFE, the DFE performance will be higher than in case he has a critical attitude.*

The attitude of the company's representative towards DFE is measured by:

- The extent to which he claims his attitude is a very responsive one or one that rejects DFE.

Additionally studied representative's characteristics

Additional attention will be given to an exploratory study of the following assumptions (not included in the research model):

- The representative's appreciation of the IC EcoDesign project: a company's representative who is highly appreciative of the IC EcoDesign project contributes towards a high level of DFE performance.
- Impact of the company representative's position: if the company's representative has sufficient decisional power to act as a change agent, DFE performance will be higher than if his decisional powers are limited.

4.2.5 Intervention characteristics and company DFE performance

A specific target was defined for each Innovation Centre (IC) setting out the number of companies that would be involved in the IC EcoDesign project. This number ranged from four (for ICs in regions with little industrial activity) to twelve (in regions where relatively many SMEs were established).
In the ideal situation, the Environmental Innovation Scan was to be used in companies which already had redesign plans for a product or the development of a new one. However, it was more difficult to get SMEs to become interested in participating in the IC EcoDesign project than expected. Consequently, the selection criteria were not always strictly applied. As a result, even some companies which did not focus on product development but on production, assembly, packaging or selling products, were included in the project instead.
Another consequence was the inclusion of companies which, although they did develop their own products, had little ambition in terms of product development at the moment of intervention. Consequently, the assumption is that if the IC consultant performs the Environmental Innovation Scan at the moment when the company has high innovational ambitions, the result of intervention in terms of DFE performance will be high. This leads to the following hypothesis, hypothesis 6.

Hypothesis 6 *Only if a IC consultant enters a company at such a time when the company's innovative ambitions are high, will the intervention lead to a high level of DFE performance.*

The innovational ambitions of a company at the moment of intervention is measured by:

- The R&D planning for the product selected: if there were plans to redesign the product or was actually being redesigned at the moment of intervention, innovational ambitions were high.
- If the product concerned had been selected because it was ready for a (major) redesign, this displays a high level of innovational ambition.

Additionally studied characteristics

One of the conclusions of Buijs' empirical study into the effectiveness of interventions for the purpose of enhancing innovation in industrial companies was that the consulting method used had an effect on the project results (Buijs, 1984). Buijs distinguished three kinds of consulting: process-consulting, programmatic-consulting or expert-consulting. The process-consulting consultants achieved the best results. However, in the IC EcoDesign project the group of consultants is expected to be slightly more homogeneous than the group included in the Pii-b project studied by Buijs. All consultants in the IC EcoDesign project had been working for the Innovation Centre Network for some years. Because they all belonged to the same IC network they had received more or less the same consultancy training, coordinated by the IC network. Moreover, their training in the field of DFE in general and their training in how to use the method developed specially for the IC EcoDesign project was exactly the same. Therefore, we may assume that the IC consultants have - to a limited extent - a common consulting style, that in the words of Buijs' could be characterized as 'process-consulting'.

However, we cannot deny that the IC consultants differed in the extent to which they were able to inspire a company to assess the DFE contribution towards the quality of its products, and to convince them to study the feasibility of the suggested DFE improvement options and to eventually implement some of them. It is assumed that IC consultants who are enthusiastically involved in the IC EcoDesign project and who believe in its benefits will be both inspiring and convincing. The companies that were advised by this type of consultants may display a higher level of DFE performance than companies advised by passive consultants with a critical attitude towards DFE. It is important to keep these divergent styles of consulting with regard to DFE in mind; however, a detailed study of the effects of consulting style is not in line with the objectives of this study. Instead, the subject is dealt with in an exploratory setting; in order to learn whether there are any systematic differences in DFE performance as a result of the IC consultant involved, the influence of the IC consultant will be explored by looking at the DFE performance of companies belonging to a certain IC region, and by comparing the results among the different IC regions.

In an exploratory setting the impact of the following innovation characteristics (not included in the research model) will be studied additionally:

- The regional innovation centre which employed the IC consultant.

° The company showed an interest in participating in the IC EcoDesign project because of the related subsidy system.

° The company showed an interest in the IC EcoDesign project because the representative did not wish to disappoint his IC consultant.

.2.6 Research model B

In the preceding sections, research focus B was worked out into four hypotheses and various additional research questions which have not been not tested as such but explored. Integrating these four hypotheses into research focus B creates the second model in this research: research model B. This model is illustrated in Figure 4.11.

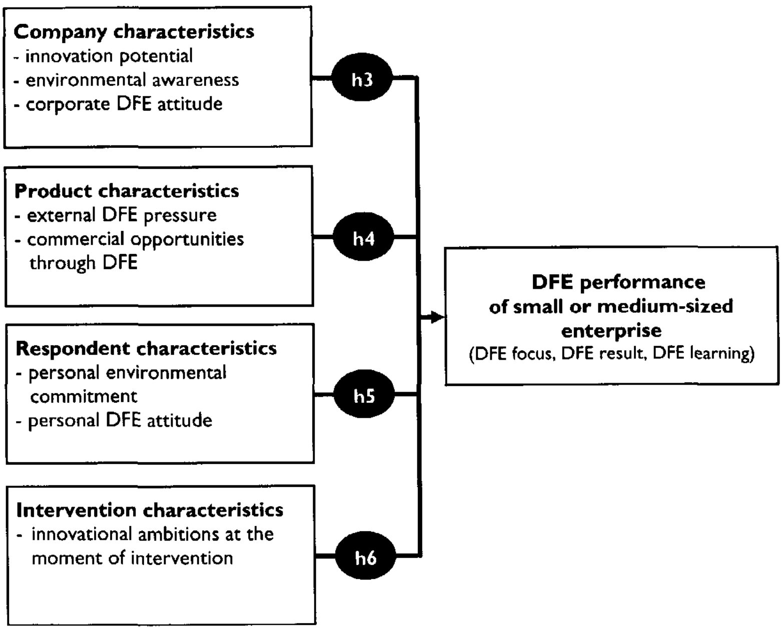


Figure 4.11 Research model B with hypotheses 3 to 6 (h3 to h6)

This chapter therefore results in the elaboration, into the research models A and B, of the two research foci introduced in Chapter 1. The latent dependent variable of DFE performance, as shown in Figure 4.11, was already operationalized in Chapter 3. If this operationalization (including hypothesis 1) is combined with research model B, then the result is Figure 4.12. This complete research model is a combination of research model A and research model B and represents the conceptual model for this study.

Of course there is a connection between the two research foci A and B. The company characteristics, the characteristics of the product involved in the Environmental Innovation Scan, those of the respondent, and the external and internal stimuli and barriers (as perceived by the respondent) are not independent of one another. For example, if the product involved is packaging or belongs to the 'brown and white goods' product group (refrigerators, dishwashers, television sets, etc.) there is a high chance that the respondent will state 'government regulations' as an external stimulus for the DFE improvement options the company has prioritized. If the product had not been redesigned for a long time, the Environmental Innovation Scan could offer a good opportunity to reduce costs; 'cost reduction' will then probably be mentioned as an internal stimulus for the product's environmental improvement. However, assessment of the relationship between the stimuli and barriers for each DFE principle mentioned by a specific company (research focus A) and the data on corporate characteristics and stimuli and barriers for DFE in general (research focus B) goes beyond the objectives of this study.

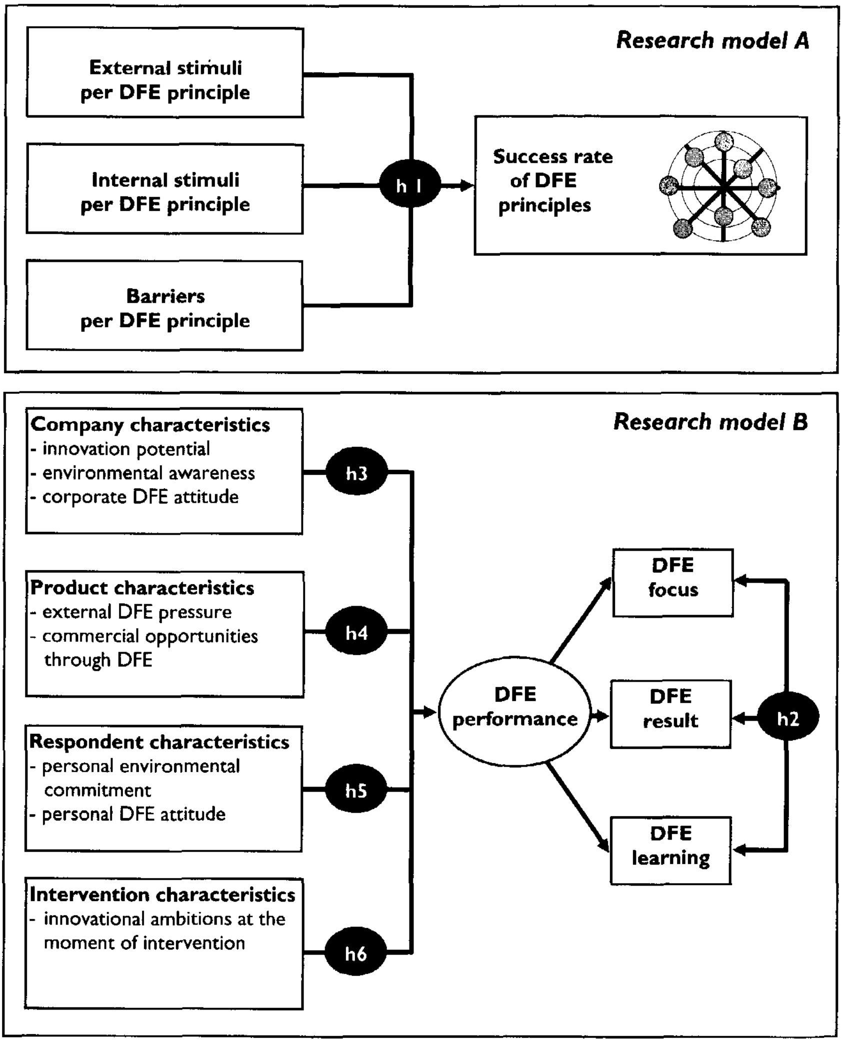


Figure 4.12 *The conceptual research model of this study: a combination of research models A and B*

5. Empirical results: DFE priorities and DFE performance

This chapter will provide the answers to the following questions: "How does the success of the DFE strategies and principles distinguished differ?" and "What are the differences in DFE performance of the participating companies?" Section 5.2 explains the differences in success of the 33 DFE principles that were distinguished in the typology of DFE strategies and principles. The following three sections subsequently present the DFE performance of the companies as a result of the IC EcoDesign project. In Chapter 3 the DFE performance was operationalized by means of three dependent variables: DFE focus, DFE result and DFE learning. Section 5.3 describes the DFE focus prioritized by the participating SMEs. Section 5.4 presents the DFE result as achieved by the SMEs, thanks to the IC EcoDesign project. Section 5.5 focuses on the SMEs' DFE learning. The results presented in these three sections are then combined in Section 5.6 which reflects on hypothesis 2.

5.1 Introduction

The preceding four chapters set the theoretical framework for the study reported on in this thesis. The core of that theoretical framework is the conceptual research model which identifies six hypotheses. This model, which is a combination of research models A and B, is illustrated in Figure 4.12 in Chapter 4. The six hypotheses are used to answer the following two central research questions:

A. Why are some directions in the field of design for environment more successful than others?
B. Why do certain small companies perform well in design for environment while others lag behind?

Before we can attempt to understand why certain DFE principles are more successful than others, and why certain SMEs have a higher DFE performance rate than others, we must know how to measure the success of DFE principles and DFE performance. Chapter 2 introduced a typology of DFE strategies and DFE principles which enabled us to typify the DFE options prioritized by the companies as a result of the IC EcoDesign project. Chapter 3 presented a method for measuring the success of DFE principles and a method for measuring the DFE performance of the companies participating in the IC EcoDesign project. The following sections present the empirical data, generated by using the measuring instruments mentioned above.

5.2 How successful are the various DFE principles?

5.2.1 Introduction

In 1995 a total of 94 SMEs participated in the IC EcoDesign project. Of these, 77 were included in the study presented in this thesis. The data were generated by two different methods: interviews and a written questionnaire. Companies were interviewed over the telephone in order to assess their DFE focus and DFE result. Further, they were asked to complete a questionnaire for the purpose of recording their DFE learning. Not all 77 companies were willing to comply with both requests. Of the 77 companies covered in this study, a total of 74 were interviewed; 75 completed the questionnaire.

Following the IC EcoDesign project, each company had received a so called 'DFE action plan', listing all the relevant DFE improvement options suggested by the IC consultant. These DFE improvement options were assessed one-by-one during the telephone interviews. The list of questions asked in connection with each DFE improvement option, plus the response codes, are given in Appendix A. These questions related to the following subjects.

Type of DFE principle of the DFE improvement option in question

The IC consultants had already typified the suggested DFE improvement options in accordance with the DFE strategy typology while drawing up the DFE action plans for the participating companies. The typology used (explained in Chapter 2) includes 33 different DFE principles, clustered into 8 DFE strategies. These strategies and principles are listed in Figure 5.1 below. The DFE strategies are set against a gray background, heading the relevant DFE principles. Note that the separate category 'DFE actions' relates to suggestions from the DFE action plan which do not relate directly to the specific product's design, its packaging or production process. Instead, they refer to the total product range of a company, and cover more general DFE-related topics like managerial, legislative or market issues.

In order to ensure legibility of this overview's the IC consultants typified the DFE improvement options at DFE strategy level, and not at the more detailed DFE principle level. At a later stage, all options were typified at DFE principle level in order to create a database of DFE improvement options. This database would then help IC consultants to generate DFE improvement options for other companies.
With a view to this research, it was necessary to ensure that all options were typified consistently in the DFE strategy typology. To guarantee that the DFE improvement options were typified as intended, the author of this thesis checked the typification of all DFE improvement options suggested.

1	**Selection of low-impact materials**
1.1	Clean materials
1.2	Renewable materials
1.3	Low energy content materials
1.4	Recycled materials

2	**Reduction in materials used**
2.1	Reduction in weight
2.2	Reduction in volume

3	**Optimization of production techniques**
3.1	Clean production techniques
3.2	Fewer production steps
3.3	Low/clean energy consumption
3.4	Less production waste
3.5	Few/clean production consumables

4	**Optimization of distribution system**
4.1	Less/clean/reusable packaging
4.2	Energy-efficient mode of transport
4.3	Energy-efficient logistics

5	**Reduction of impact during use**
5.1	Low energy consumption
5.2	Clean energy source
5.3	Few consumables needed
5.4	Clean consumables
5.5	No waste of energy/consumables

6	**Optimization of initial lifetime**
6.1	High reliability and durability
6.2	Easy maintenance and repair
6.3	Modular /adaptable product structure
6.4	Classic design
6.5	Strong product-user relation

7	**Optimization of end-of-life system**
7.1	Reuse of product
7.2	Remanufacturing/ refurbishing
7.3	Recycling of materials
7.4	Safe incineration (energy recovery)
7.5	Safe disposal of product remains

@	**New concept development**
@.1	Dematerialization
@.2	Shared product use
@.3	Integration of functions
@.4	Functional optimization

DFE actions[1]	
	Improved management practices
	Development of take-back system
	Industrial ecology
1) DFE actions are managerial, non-technical issues (not related directly to product /packaging/production)	

Figure 5.1 The typology of 33 DFE principles, clustered in 8 DFE strategies as distinguished in this study

Success rate of the DFE improvement option

The question asked was: To what extent has the DFE improvement option been realized, or in other words: what is the success rate of the specific DFE improvement option? Chapter 3 distinguished a total of nine success rates, which were set out in Figure 3.5 in Chapter 3. A DFE option could either be 'rejected' (success rate 0), 'of interest' (success rate 1, 2 or 3), 'prioritized' (success rate 4, 5 or 6) or 'not considered' (success rate 7 or 8). If a DFE option was already 'realized' it was rewarded success rate 6.

The newness of the DFE improvement option

The question here was: What was the additional value of the DFE improvement option, or in other words: what is the newness of the specific DFE improvement option? As explained in Chapter 3, three degrees of newness are distinguished. These were listed in Figure 3.6 in Chapter 3. The newness can either be 'limited' (newness of 1), 'fair' (newness of 2) or 'high' (newness 3).

.2.2 Types, success rates and newness of the studied DFE improvement options

As many as 596 DFE improvement options were suggested in the DFE action plans for the 77 companies studied. Only after the researcher had typified each of the 596 DFE improvement options did it become possible to generate an overview of the frequency of the suggested DFE improvement options. This overview is shown in Figure 5.2 in which the columns are stacked according to the success rates of the DFE improvement options.

Figure 5.2 leads to the following conclusions:

- *At the time the interviews were held, a total of 183 (31%) of the 596 DFE options suggested by the IC consultants were given success rate 6, meaning that these options had already been realized or would be realized very soon. 'Realized' here means that the DFE option suggested had been incorporated in the product's design, packaging or production processes. It also means that the environmentally improved product was already being marketed or the company was convinced that it would be launched very soon.*
- *As many as 247 of the 596 DFE options suggested by the IC consultant were prioritized: they were given success rate 4, 5 or 6. This means that they had already been realized (success rate 6; the 183 DFE options mentioned above) or would be realized within one (success rate 5) or three years (success rate 4). Thus a total of 247 of all 596 DFE options suggested (41%) will be realized within three years of the research project.*

Do these figures indicate that the IC EcoDesign project was a success? If we compare these results with the scores of the preceding, successful PRISMA project, then the answer must be in the affirmative. The Dutch PRISMA project for the prevention of waste and emissions covered ten industrial companies. Although this was a project that focused on process rather than product improvements, the intervention and evaluation methodologies are comparable with the ones used in the IC EcoDesign project. The PRISMA project came up with a total of 164 improvement options (De Hoo, 1991). Of these, 45 (27%) were implemented at the moment the evaluation took place (similar to our 'were realized'). A total of 65 options (40%) were judged as feasible (similar to our 'were prioritized'). We may therefore conclude that the IC EcoDesign project was at least as successful as its predecessor, the PRISMA project.

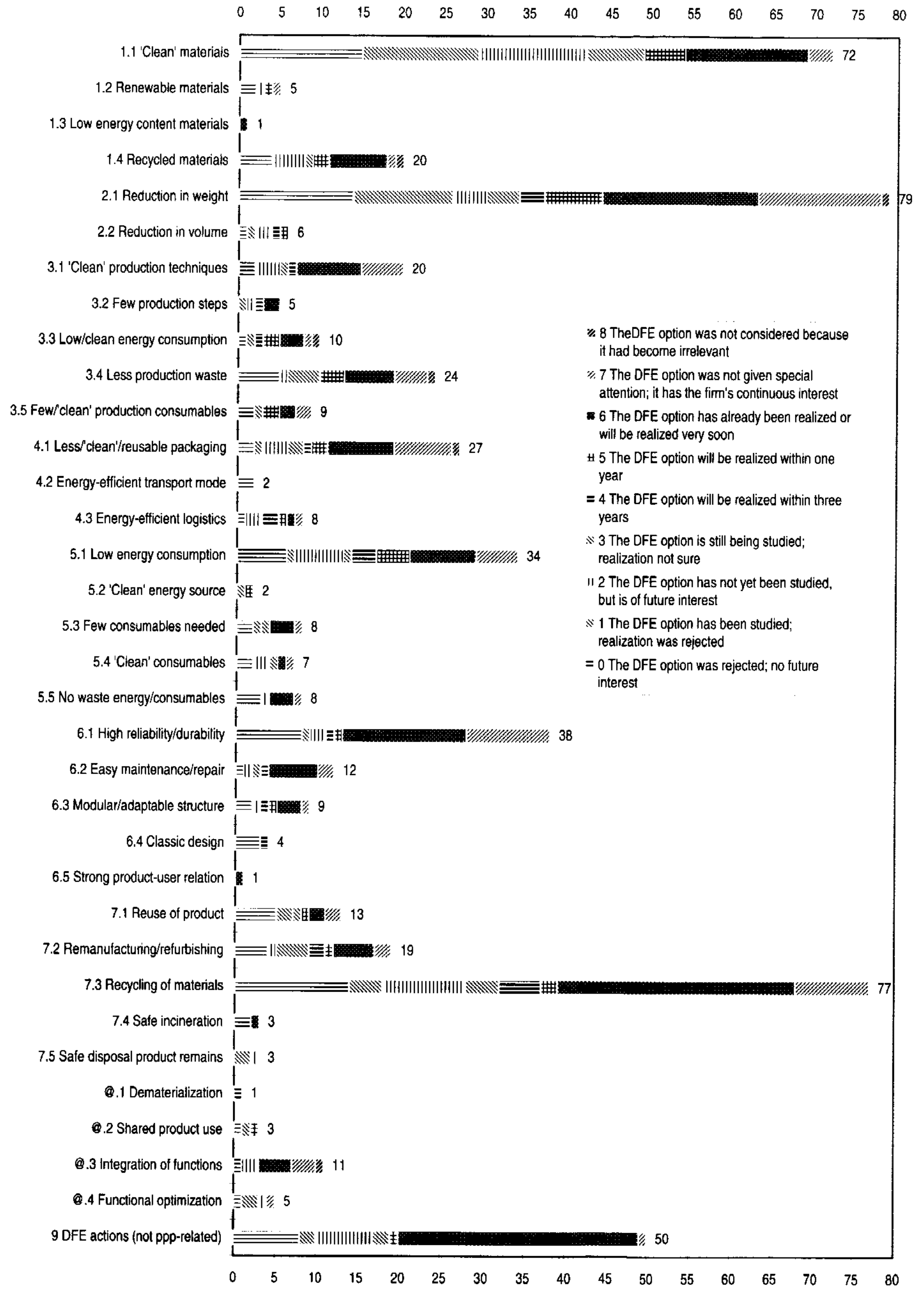


Figure 5.2 *The number of suggested DFE improvement options, categorized according to the typology of DFE strategies and principles, stacked according to grade of realization*

The most frequently suggested DFE principles

As expected, we see considerable differences regarding the absolute numbers of DFE options belonging to a certain type of DFE principle. The ten most frequently suggested DFE principles, (according to the number of times DFE options of the type of DFE principle were suggested) are listed in Figure 5.3 below.

DFE principle	Description	Suggestion frequency
2.1	Reduction in weight	79
7.3	Material recycling	77
1.1	'Clean' materials	72
6.1	High reliability/durability	38
5.1	Low energy consumption	34
4.1	Less/'clean'/reusable packaging	27
3.4	Less production waste	24
1.4	Recycled materials	20
3.1	'Clean' production techniques	20
7.2	Remanufacturing/refurbishing	19

Figure 5.3 *The ten most often suggested DFE principles, according to the number of DFE options of the specific type of DFE principle suggested in the DFE action plans*

Figure 5.3 intentionally fails to list the category of 'DFE actions' even though as many as 50 DFE options of this type had been suggested. The reason for these not to be given further study is that the DFE actions in question do not relate directly to the product's design, its packaging or the production processes. These are actions that relate more to general issues like managerial procedures which only have an indirect effect on the product and the packaging design. Some typical DFE actions are:

- Obtain information about product-oriented environmental regulations in export countries;
- Research the market in order to learn about the environmental demands of retail and end-users;
- Perform a benchmark study to find out the extent to which competitors apply DFE to their products;
- Contact the company's suppliers to obtain environmental information about components or materials;
- Start the process for obtaining an eco-label;
- Make one person in the company responsible for all environmental affairs;
- Integrate DFE into the company's product development process.

This study focuses on DFE principles that imply environmental product, packaging and production improvements. DFE actions which do not represent product-specific issues are not considered. Nevertheless, the empirical data collected could be of future interest should we wish to study the interaction between DFE and EMS (corporate environmental management system).

Figure 5.2 and Figure 5.3 lead us to the conclusion that three DFE principles were suggested far more frequently than others. Furthermore, there is a contrast between the ten DFE principles mentioned above and the other 22 DFE principles (suggested 13 times at most). As we can see from the number of times the different principles were suggested, there is a considerable difference in terms of their 'popularity'.

The most successful DFE principles

Can we state that those DFE principles suggested most frequently were also very successful? In this thesis a DFE option is only regarded as successful if it was prioritized by the company concerned: the DFE option was attributed with success rate 4, 5 or 6, implying its realization within a period of three years. A DFE principle is therefore ***successful*** if a relatively large number of DFE options of the specific type of DFE principle had been prioritized, and had thus been given a success rate of 4, 5 or 6.

To establish the success of a specific DFE principle we must compare the number of prioritized DFE options (success rate 4, 5 or 6) with the number of DFE options that were suggested. If we first of all concentrate on the ten most frequently suggested DFE principles mentioned above, we see the success percentages listed in Figure 5.4 below.

DFE principle	Description	Suggestion frequency	% of DFE options prioritized
7.3	Recycling of materials	77	47%
6.1	High reliability/durability	38	45%
1.4	Recycled materials	20	45%
5.1	Low energy consumption	34	44%
7.2	Remanufacturing/refurbishing	19	42%
3.4	Less production waste	24	38%
3.1	'Clean' production techniques	20	38%
2.1	Reduction in weight	79	37%
1.1	'Clean' materials	72	28%
4.1	Less/'clean'/reusable packaging	27	26%

Figure 5.4 The percentages of prioritized DFE options (success rate 4, 5 or 6) and the suggestion frequency for the ten most frequently suggested type of DFE principle

Figure 5.4 shows that Recycling of materials (DFE principle 7.3) was without doubt the most successful one: it was the one most frequently suggested *and* prioritized. There were two other DFE principles which were also successful and often suggested: DFE principle 6.1 'High reliability/durability' and DFE principle 5.1 'Low energy consumption during use'.

We also found that the ten most frequently suggested DFE principles were also the most successful ones as well. However, the most frequently suggested DFE principles are not automatically the ones that were most frequently prioritized. For example, whereas options of DFE principle 2.1 'Reduction in weight' or 1.1 'Clean materials' were suggested often enough, they were prioritized less frequently.

From Figure 5.4 we can conclude that:

- *The top-three most successful* **and** *often suggested DFE principles are: (1) 7.3 'Recycling of materials', (2) 6.1 'High reliability/durability' and (3) 5.1 'Low energy consumption during use'.*
- *The companies studied gave most of their attention to end-of-life issues (recycling of materials, remanufacturing/refurbishing), to reducing the product weight, and to the use of 'clean' (non-hazardous) and recycled materials. Other important topics were the increase of product durability, reducing the product's energy consumption and cleaner technology (less production waste and 'clean' production techniques). Finally, product packaging was also an important environmental concern.*

Do these findings match others reported in literature? Smith et al. (1996:24) carried out interviews in sixteen British, American and Australian companies, ranging from small to large, selected on grounds of their 'green product initiatives'. They concluded that the companies in question were most often concerned with:

1. Choice of materials (corresponds with DFE strategy 1: 'Selection of low-impact materials');
2. Reducing the environmental impacts of production (corresponds with DFE strategy 3: 'Optimization of production techniques);
3. Reducing the energy and pollution impacts of the product in use (corresponds with DFE strategy 5: 'Reduction of impact during use');
4. Recycling materials at the end of the product's life (corresponds with DFE principle 7.3: 'Recycling of materials').

Comparing these four foci in DFE with the DFE principles listed in Figure 5.4 we see that the four foci are indeed represented in the group of ten DFE principles suggested most frequently *and* prioritized in the present study. There are some differences as well: first, the ranking is different. For example, in the present study, DFE principle 7.3 'Recycling of materials' was more dominant than in the UK study. Furthermore, some DFE principles that were given a great deal of attention in the IC EcoDesign study were not included in the four foci mentioned above. There are many reasons for these differences. They might be due to geographical differences or different national legislation. They could be due to the fact that the IC EcoDesign study focuses on companies employing a workforce of up to 200 and the UK study includes small as well as large companies. Or, and this is the most probable reason, due to differences in the typologies of DFE options that were applied. However, a more detailed comparison of the two studies is not justified because of the divergent research methods and companies studied.

Hanssen (1997) reports the results of the Nordic Project on Environmentally Sound Product Development (NEP project), to stimulate six Nordic companies to apply DFE. In the last paper of his thesis, Table 1, he lists the 'Proposed or realized options for improvement of analyzed products'. A total of 15 options were listed for six products. Three concerned improvements which did not relate to product design: Change external system conditions (mentioned twice) and Change voltage in distribution system (once, for electric cables). The following options, focusing on product improvement options, were listed:

- Substitution of raw materials (5 times), corresponding with DFE strategy 1 'Selection of low-impact materials';
- Use recovered material (3 times), corresponding with DFE principle 1.4 'Recycled materials';
- Recover material after use (twice), corresponding with DFE principle 7.3 'Recycling of materials';
- Use less materials (once), corresponding with DFE strategy 2 'Reduction of materials usage';
- Increase the wattage of individual fluorescent tubes so fewer fittings are required per unit (once), encompassed in DFE strategy 2 'Reduction of materials usage'.

A comparison of these improvement options with Figure 5.4 shows that the NEP option types are also represented in the group of ten most frequently suggested and successful DFE principles listed in Figure 5.4. Here again do we see differences in ranking and number of successful DFE principles. Due to differences, among other things in typology of the DFE improvement options used and the number, type and size of companies investigated in the two studies, we should refrain from making any further comparison. Figure 5.5 summarizes the findings of the IC EcoDesign study, of Smith et al. (1996) and Hanssen (1997).

DFE principle	Description	Van Hemel	Smith et al.	Hanssen
7.3	Recycling of materials	●	●	●
6.1	High reliability/durability	●		
1.4	Recycled materials	●		●
5.1	Low energy consumption	●	●	
7.2	Remanufacturing/refurbishing	●		
3.4	Less production waste	●	●	
3.1	'Clean' production techniques	●	●	
2.1	Reduction in weight	●		●
1.1	'Clean' materials	●	●	●
4.1	Less/'clean'/reusable packaging	●		

Figure 5.5 *Comparison of the most successful DFE principles found by Van Hemel (this thesis), Smith et al. (1996) and Hanssen (1997)*

Figure 5.5 shows that the three studies only agree on the point that dominant DFE principles turn out to be 7.3 'Recycling of materials' and 1.1 'Selection of 'clean' materials'. Three DFE principles were found to be important in the IC EcoDesign project, but were not mentioned in the other two studies. This concerns the DFE principles 6.1 'High reliability/durability', 7.2 'Remanufacturing/refurbishing' and 4.1 'Less/clean/reusable packaging'. However, as mentioned above, we should not take our comparison too far. This would not justified due to considerable differences in research methodology, the DFE typologies used and the number, type and size of the companies investigated in the three studies. To enable comparison in future research on DFE implementation, the use of a common typology of potential directions for DFE improvement is recommended.

Successful but less frequently suggested DFE principles

Figure 5.2 sets out a set of DFE principles which, although they were not suggested very often, were prioritized with a relatively high frequency. These DFE principles with a low suggestion frequency but high success percentages are listed in Figure 5.6. DFE principles suggested less than five times were omitted in order to prevent unreliable conclusions. DFE principles with DFE options that were prioritized below 40% are not included in Figure 5.6 either.

DFE principle	Description	Suggestion frequency of	% of DFE options prioritized
3.2	Few production steps	5	60%
3.3	Low/'clean' energy consumption	10	60%
6.2	Easy maintenance/repair	12	58%
6.3	Modular/adaptable structure	9	56%
4.3	Energy efficient logistics	8	50%
3.5	Few/'clean' production consumables	9	44%

Figure 5.6 DFE principles prioritized relatively often, even though they had not been frequently suggested

Figure 5.6 reveals that very successful, but less frequently suggested DFE principles were 'Few production steps', 'Low/clean energy consumption in production phase', 'Easy maintenance and repair' and 'Modular/adaptable product structure'. This implies that whenever such a DFE option was suggested, the likelihood of it being prioritized was high.

In conclusion we can safely state that:

- *The 16 DFE principles listed in Figure 5.4 and Figure 5.6 are obviously more successful than the other 17 DFE principles distinguished in the typology of DFE strategies and principles used in this thesis.*
- *DFE strategies that were given less attention are DFE strategy 5 'Optimization of initial life time' (with the exception of DFE principle 5.1 'Low energy consumption during use'), and DFE strategy @ 'New concept development'.*

The question that then follows is: How can we explain these differences in success among the 33 DFE principles? Chapter 1 presented this question as central research question A. In Chapter 4 it was elaborated into research model A with hypothesis 1, and in Chapter 6 we will test hypothesis 1 by means of empirical data. If hypothesis 1 is supported by empirical data, we can then give a rough answer to the question how to explain the major difference in the success rate of the 33 DFE principles reported in this section.

Newness or additional value of the DFE options

Next, Figure 5.7 reveals the extent to which the 596 DFE options suggested were new for the companies investigated. In case a company's representative perceived a DFE option as 'new', implying that the option had not been thought of before, then that option had a high additional value (newness 3, see Figure 3.6 in Chapter 3). Conversely, if the company had stated that it would have considered the DFE option in question whether or not it had participated in the IC EcoDesign, the option had a low additional value (newness 1, see Figure 3.6 in Chapter 3).

Figure 5.7 leads to the conclusion that the additional value of most DFE options is 'fair' to 'high'. With respect to most types of DFE principle, about one-third of the options was new for the company (newness 3), one-third was already known (newness 2) and one-third would have been considered anyhow (newness 1).

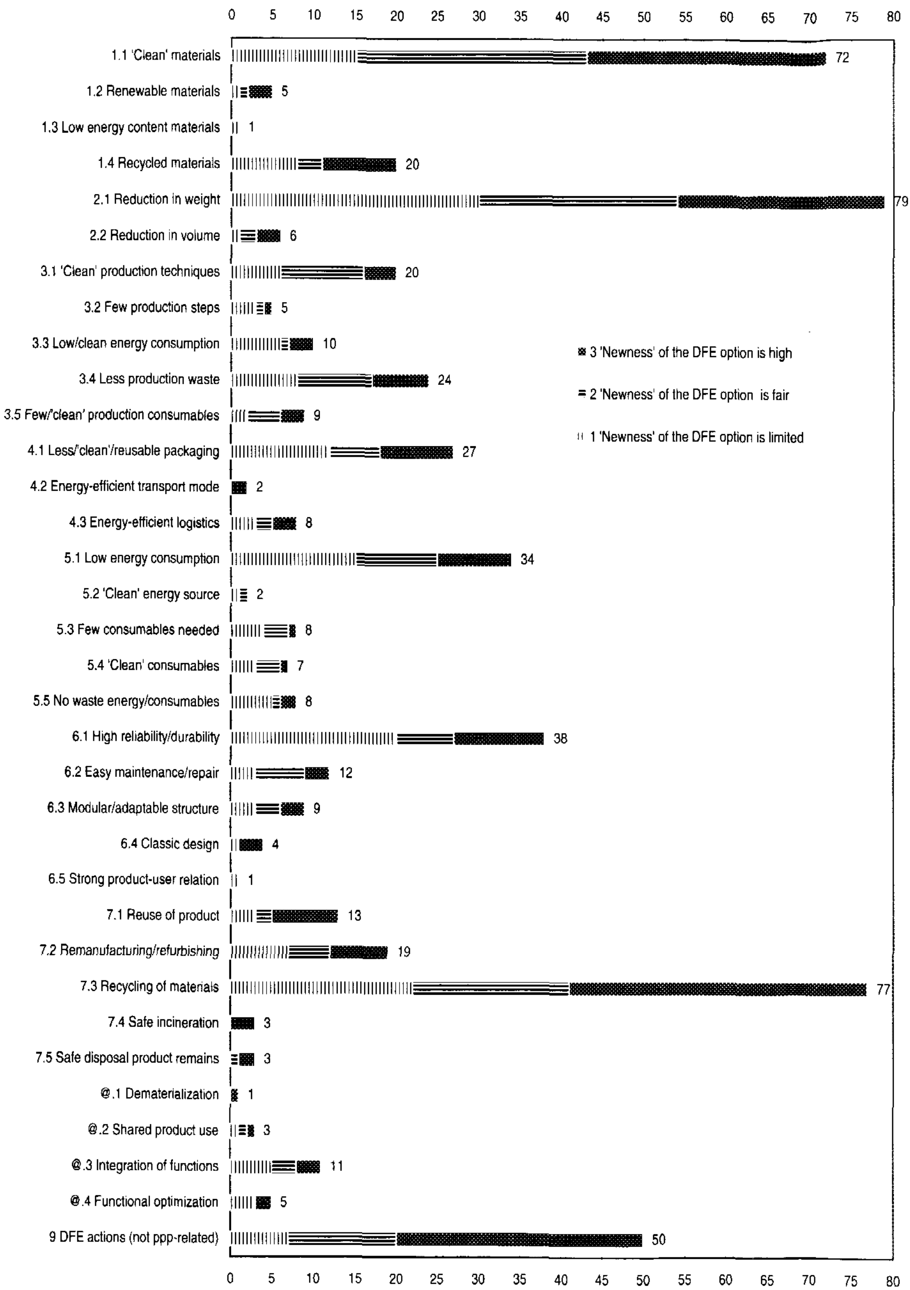


Figure 5.7 *The number of suggested DFE improvement options, categorized according to the typology of DFE strategies and principles, stacked according to 'newness' for the company*

The number of DFE options per DFE principle with newness 1 is indicative of the extent to which the company was already familiar with the DFE principle in question. Some DFE principles seem to be relatively new for the companies concerned; others being relatively familiar. Figure 5.8 sets the new DFE principles against those that are more familiar.

New DFE principles (newness 3)	
DFE principle	% of options prioritized
1.1 'Clean' materials	28%
1.2 Renewable materials	20%
2.2 Reduction in volume	33%
3.5 Few/'clean' production consumables	44%
6.2 Easy maintenance/repair	58%
6.4 Classic design	25%
7.1 Reuse of product	23%
7.4 Safe incineration	33%

Familiar DFE principles (newness 1)	
DFE principle	% of options prioritized
2.1 Reduction in weight	37%
3.2 Few production steps	60%
3.3 Low/clean energy consumption during production	60%
4.1 Less/'clean'/reusable packaging	26%
5.1 Low energy consumption during use	44%
5.2 Few consumables needed during use	50%
5.5 No waste of energy/consumables during use	38%
6.1 High reliability/durability	45%
@.3 Integration of functions	36%

Figure 5.8 New DFE principles (newness 3) versus familiar (newness 1) DFE principles

It is obvious that DFE principles like 'Reduction in weight', 'Few production steps', 'High reliability/durability' and 'Integration of functions' are already familiar to many companies. They represent product requirements which are common in product development, even beyond the perspective of environmental considerations. We expect that many of these DFE principles (leading to synergy with more familiar product requirements) will be prioritized. Furthermore, we expect the DFE options of those types of DFE principle which are relatively new to the companies to obtain relatively lower success rates.

Figure 5.8 also shows the percentages of DFE options prioritized per DFE principle. It is only natural that the percentages in the right column are - with three exceptions - higher than those in the left column. For the time being this supports our assumption that DFE principles which are less compatible with 'traditional' product requirements have a lower chance of being prioritized than DFE principles which lead to synergy. The question why certain DFE principles are more successful than others will be explained in more detail in Chapter 6.

In total, as many as 227 of the suggested 596 DFE options (38%) were said to be totally new for the companies (newness 3); 169 (28%) were said not to be new, but would not have been reconsidered if the company had not participated in the IC EcoDesign project (newness 2). Focusing on the 247 prioritized DFE options, 62 (25%) were totally new (newness 3) and 91 (37%) were reconsidered thanks to the IC EcoDesign project (newness 2): in total 62% of the prioritized 247 DFE options were prioritized partly as a result of the IC EcoDesign project. This conclusion, in combination with the high number of prioritized DFE options (41%), justifies the conclusion that on the whole the 1995 IC EcoDesign project resulted in substantial additional value.

5.3 Company DFE performance I: DFE focus

5.3.1 Introduction

By using the DFE action plans developed for each of the participating SMEs, we first obtained an impression of the focus of the individual companies with regard to DFE. During the monitoring research, all companies were asked to what extent they had realized the DFE improvement options suggested in the DFE action plan. The response showed that while certain DFE options had been prioritized others had been rejected. This enabled us to identify in more detail the focus of the individual companies regarding DFE. This led to an interesting question: can we group companies in clusters according to the type of DFE focus manifested as a result of the IC EcoDesign project? In other words: are there any patterns to be distinguished amongst the participating SMEs when comparing their DFE foci? This research question, answered below, was already formulated in Chapter 1 and formed the basis for hypothesis 2 (see Chapter 4).

5.3.2 How to identify a company's DFE focus?

In order to answer this question, the DFE foci of the participating companies were compared by using statistical analysis techniques. As mentioned in the above, a total of 596 DFE improvement options had been suggested to the SMEs. The success rates of these options, recorded during the interviews, ranged from 0 to 8 (see Figure 3.5 in Chapter 3). To identify the companies' individual DFE focus it was decided to take into account only those DFE improvement options that were prioritized by the SMEs. As Figure 3.5 indicates, the expression 'prioritized' means that the options had already been realized (success rate 6), that they would be realized within one year (success rate 5) or within three years from the moment the interview had taken place (success rate 4). Consequently, the ***DFE focus*** of a company was defined as the set of DFE principles it had prioritized for realization within a period of three years.

To construct a company's DFE focus, not only the DFE options with a success rate other than 4, 5 or 6 were excluded, but also the so called 'DFE actions'. DFE actions relate to a company's total product range or to more general DFE-related topics like legislation and market issues. As a result, only those DFE improvement options that related to the actual product, packaging or production processes were used to describe a company's DFE focus. Implementation of these two selection criteria resulted in a selection of 216 DFE improvement options from the 596 in total.

Furthermore, whenever a company realized more than one DFE improvement option of a specific type of DFE principle, only the first was taken into account for pragmatic reasons. Hence if a company had two DFE improvement options of the type 1.1 (Clean Materials), this DFE option was listed only once in the SPSS data matrix in order to facilitate a statistical cluster analysis. As a result, the number of prioritized DFE improvement options considered in this analysis dropped from 216 to 188. As many as 60 of the 77 companies studied had prioritized at least one DFE improvement option by giving it a success rate of 4, 5 or 6.

The question whether a DFE option was totally new or familiar to a company was not taken into account in this analysis. A company's DFE focus should encompass DFE options which are either totally new or which it would still have considered had it not participated in the IC EcoDesign project. Therefore, we must acknowledge that a company's DFE focus is not exclusively the result of the IC EcoDesign project, but can also include its DFE initiatives prior to participation in the IC EcoDesign project.

5.3.3 The result: eight DFE focus clusters

A cluster analysis (hierarchical cluster analysis, using Ward's method) was performed to learn whether we could group the sixty remaining companies into clusters according to DFE focus. The aim of a cluster analysis is to construct the least possible clusters; each cluster must, however, be sufficiently homogeneous.

An indication of a cluster's homogeneity is the so-called 'Euclidean distance coefficient'. This coefficient increased considerably when a five-cluster solution was compared with a four-cluster solution. This means that the five clusters in the five cluster solution are considerably more homogeneous than the four clusters in the four cluster solution. Therefore, the minimum number of clusters that can be distinguished is five. When the number of clusters was increased from five to six, the Euclidean distance decreased considerably, meaning that the homogeneity within the clusters increased strongly for a second time. The last time a sudden decrease was noted in the Euclidean distance was when the number of clusters was increased from seven to eight. When the number of clusters was increased up to nine and beyond, the steps with which the Euclidean distance decreased became considerably smaller. This means that the pace at which the homogeneity within the clusters increased slowed down. To be able to interpret the distinguished clusters, the number of clusters should be as small as possible. We therefore decided to stick to eight so-called 'DFE focus clusters'.

Figure 5.9 presents the result of the cluster analysis, showing the frequency of the DFE improvement options prioritized in each of the eight DFE focus clusters. The options are typified according to the 33 DFE principles distinguished in the DFE strategy wheel.

DFE principle		Cl. 1	Cl. 2	Cl. 3	Cl. 4	Cl. 5	Cl. 6	Cl. 7	Cl. 8
1.1	Clean materials	3	1	13	0	0	0	1	0
1.2	Renewable materials	0	1	0	0	0	0	0	0
1.3	Low energy content materials	0	0	0	0	0	1	0	0
1.4	Recycled materials	0	2	1	1	0	[illegible]	2	0
2.1	Reduction in weight	11	0	1	1	[illegible]	2	[illegible]	0
2.2	Reduction in volume	0	0	1	0	1	0	0	0
3.1	Clean production techniques	1	1	3	0	[illegible]	0	0	0
3.2	Fewer production steps	0	0	1	0	1	1	0	0
3.3	Low/clean energy consumption	2	0	0	0	0	[illegible]	1	0
3.4	Less production waste	[illegible]	0	1	1	0	0	1	0
3.5	Few/clean production consumables	1	1	1	0	0	0	0	0
4.1	Less/clean/reusable packaging	2	0	1	2	0	2	0	4
4.3	Energy-efficient logistics	[illegible]	0	1	0	0	0	0	0
5.1	Low energy consumption	0	2	1	[illegible]	0	1	[illegible]	0
5.2	Clean energy source	0	1	0	0	0	0	0	0
5.3	Few consumables needed	0	0	1	0	0	1	0	0
5.4	Clean consumables	0	0	0	0	0	0	1	0
5.5	No waste of energy/consumables	1	0	0	0	0	1	1	0
6.1	High reliability and durability	1	0	4	5	2	0	3	0
6.2	Easy maintenance and repair	0	0	0	0	0	0	7	0
6.3	Modular /adaptable product structure	0	2	0	1	1	0	0	1
6.4	Classic design	0	1	0	0	0	0	0	0
6.5	Strong product-user relation	0	0	0	0	0	0	1	0
7.1	Reuse of product	0	2	0	0	1	0	0	0
7.2	Remanufacturing/ refurbishing	0	2	1	0	4	0	0	0
7.3	Recycling of materials	0	1	5	5	2	4	3	[illegible]
7.4	Safe incineration (energy recovery)	0	0	0	0	0	0	1	0
@.1	Dematerialization	0	1	0	0	0	0	0	0
@.2	Shared product use	0	0	0	0	1	0	0	0
@.3	Integration of functions	0	0	2	0	1	0	1	0
	Total	31	18	38	20	20	19	34	8
	Number of companies	13	10	13	5	4	4	7	4

1) The DFE principles 4.2, 7.5 and @.4 are absent since no DFE improvement option of these types had been prioritized

	The black cells indicate that the DFE principle plays a very important role in the specific cluster (if nearly all companies prioritized at least one DFE option of this type of DFE principle)
	The dark-gray cells indicate that the DFE principle plays an important role in the cluster (if most companies prioritized an option of this type of DFE principle / if most options mentioned in the cluster are of this type of DFE principle / if most options of this type of DFE principle are concentrated in the cluster concerned
	Hatched cells indicate that the DFE principle plays a significant role in the cluster (if many options of this type of DFE principle were realized / if many options mentioned in the cluster are of this type of DFE principle / if many options of this type of DFE principle are concentrated in the cluster concerned

Figure 5.9 *Frequency of the prioritized DFE improvement options, manifested in eight DFE focus clusters and typified according to the 33 DFE principles distinguished in the DFE strategy wheel.*

What do we learn from Figure 5.9? It supports the assumption that we can cluster the participating companies into clusters according to the number and type of DFE improvement options they prioritized. For example, in DFE focus cluster 1 the DFE principle 2.1 *Reduction in weight* plays a very important role, while in DFE cluster focus 3 DFE principle 1.1 *Clean materials* is the most dominant.

It goes without saying that we then move on to the question whether we can explain why certain companies end up in a specific DFE focus cluster. Do these companies or their products have certain characteristics in common?
An initial effort was made to identify some common characteristics of the products that belong to a certain cluster. This was done by looking simultaneously at the sort of products that belong to a specific cluster and that cluster's most dominant DFE principles.
Figure 5.10 summarizes for each cluster the DFE focus identified in Figure 5.9. Listed are the DFE strategies, the DFE principles that were prioritized in particular and the number of companies belonging to the cluster. Moreover, the last column presents certain characteristics the products seem to have in common.

Cluster	DFE focus	DFE principles in particular	# Companies	Product
Cluster 1	DFE strategy 2 DFE strategy 3 DFE strategy 4	***Reduction in weight*** Less production waste Energy-efficient logistics	13	Products which require transport, inventorial products
Cluster 2	No focus	No focus	10	Not evident
Cluster 3	DFE strategy 1 DFE strategy 3 DFE strategy 6 DFE strategy 7	***Clean materials*** Clean production techniques High reliability and durability Recycling of materials	13	Products containing 'suspicious' materials
Cluster 4	DFE strategy 5 DFE strategy 6 DFE strategy 7	Low energy consumption ***High reliability and durability*** ***Recycling of materials***	5	Energy-consuming consumer products
Cluster 5	DFE strategy 2 DFE strategy 3 DFE strategy 7	Reduction in weight Clean production techniques ***Remanufacturing/refurbishing***	4	Heavy duty, professional products
Cluster 6	DFE strategy 1 DFE strategy 3 DFE strategy 7	Recycled materials Low/clean energy consumption. ***Recycling of materials***	4	Not evident
Cluster 7	DFE strategy 2 DFE strategy 5 DFE strategy 6	Reduction in weight Low energy consumption ***Easy maintenance/repair***	7	Professional, failure-sensitive products
Cluster 8	DFE strategy 4 DFE strategy 7	***Less/clean/reusable packaging*** Recycling of materials	4	Not evident

Figure 5.10 Typification of the DFE focus in the eight distinguished DFE focus clusters; the most dominant DFE principle per DFE focus cluster is printed in bold print

We must conclude that the products belonging to a specific cluster apparently have little in common. Some similar product characteristics could be found in the case of five clusters only; the products had too little in common in the three other clusters. Furthermore, it was impossible to typify the five clusters by comparing product characteristics only, and not the prioritized DFE principles.

5.4 Company DFE performance II: DFE result

The second component of a company's DFE performance is the DFE result it achieved as a result of the IC EcoDesign project. As presented in research model B, four indicators were distinguished which, when combined, provide an insight into the DFE results of the companies studied. These four dependent variables, derived from Figure 3.4 in Chapter 3) that add up to the DFE result are:

- DFE score: The extent to which a set of DFE improvement options (suggested in the DFE action plan generated through the IC EcoDesign scan) have been realized.
- DFE project score: The extent to which a set of DFE improvement options with a high level of newness (suggested in the DFE action plan generated through the IC EcoDesign scan) has been realized.
- DFE result opinion: The opinion of the company's representative as to how much the IC EcoDesign project has led to concrete results for the product involved.

- DFE design impact:: The opinion of the researcher on the degree of innovation achieved for the product involved in the IC EcoDesign Scan.

In the following sections the scores of the companies at these four variables will be presented. To what extent these four indicators correlate mutually is discussed in the last section.

5.4.1 The DFE score

In Chapter 3 the company's DFE score was defined as the extent to which the set of DFE improvement options (suggested in the DFE action plan as a result of the IC EcoDesign scan) had been realized.

As suggested in Chapter 3, the DFE score is calculated by using the formula:

DFE score = $n * ((R_1 + R_2 + ... + R_n)/n)^2 = n * Rg * Rg$

R_1 : The success rate of option 1;

n: The number of DFE improvement options listed in the DFE action plan;

Rg: The average success rate of the DFE improvement options.

As listed in Figure 3.5 (Chapter 3) the success rates of DFE improvement options range from 0 to 8.

Let us give an example in order to demonstrate this calculation method. ICED was suggested six DFE options (n=6). The success rates for these six DFE options were 6, 5, 3, 3, 2 and 0 (respectively R_1, R_2, R_3, R_4, R_5 and R_6). The average success rate Rg of these DFE options is therefore 3.17 ((6+5+3+3+2+0/6). As a result, the DFE score of this company adds up to 60 (6*3.17*3.17).

Figure 5.17 shows the scores for DFE score given to the 77 companies studied. ICED, with its DFE score of 60, would fall in the third category.

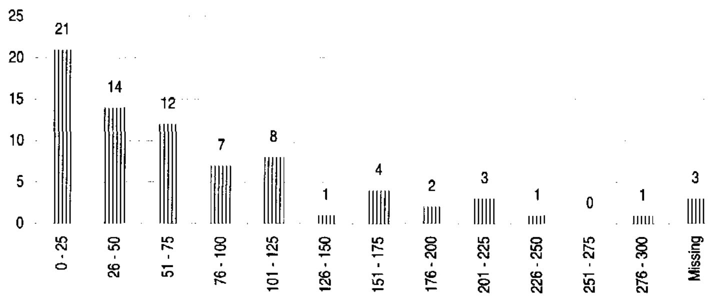


*Figure 5.11 Scores for DFE score (DFE score = n * Rg * Rg) of 77 companies*

Figure 5.11 shows that, as expected, the SMEs participating in the IC EcoDesign project differ considerably in terms of DFE score. Furthermore, about half of the companies share a relatively low DFE score with a maximum of 50. The DFE scores of the other half, between 51 and 225, are considerably higher. Two companies have exceptionally high scores between 226 and 300.

5.4.2 The DFE project score

In order to learn what the DFE result is of a company, particularly as a result of the IC EcoDesign project, another DFE result indicator was constructed: the DFE project score. This differs from the DFE score in the sense that while the DFE score includes all the suggested DFE options the DFE project score only includes those DFE options that were considered on the basis of the IC EcoDesign project (newness 2 and 3, see Figure 3.6, Chapter 3) DFE options a company would have considered regardless of the IC EcoDesign project are thus excluded (newness 1, see Figure 3.6).

Chapter 3 defined a company's DFE project score as the extent to which the set of DFE improvement options with a high degree of newness (suggested in the DFE action plan as a result of the IC EcoDesign scan) was realized.

As suggested in Chapter 3, the DFE project score is calculated by the formula:

DFE project score = $m * ((A_1 + A_2 + ... + A_m)/m)^2 = m * Ag * Ag$

A_1 : The success rate of option 1 (only DFE options with newness 2 or newness 3);

m: The number of DFE improvement options (with newness 2 or 3), listed in the DFE action plan;

Ag: The average success rate of the DFE improvement options (with newness 2 or 3).

Example: a calculation of the DFE project score of ICED (mentioned in the above). Six DFE options were suggested to this company (n=6). The success rates of these six DFE options were 6, 5, 3, 3, 2 and 0 (respectively R_1, R_2, R_3, R_4, R_5 and R_6). The average success rate Rg of these six DFE options was therefore 3.17 ((6+5+3+3+2+0)/6). The total DFE score of this company was 60 (6*3.17*3.17).

To calculate this company's DFE project score, we look at only those DFE options that were new to the company, i.e. DFE options with a newness of 2 or 3. It was only for these DFE options that the IC EcoDesign project had considerable additional value. Four of the six DFE improvement options suggested had a newness of 2 or 3 (m=4). The success rates of these four DFE options were 5, 3, 2 and 0 (respectively R_2, R_4, R_5 and R_6, now called A_2, A_4, A_5 and A_6). The average success rate Ag of these four DFE options is 2.5 ((5+3+2+0)/4). The DFE project score of ICED therefore totals 25 (4*2.5*2.5).

Figure 5.12 presents the scores for the DFE project score of those companies participating in the IC EcoDesign project. ICED, with its DFE project score of 25, would fall in the first category.

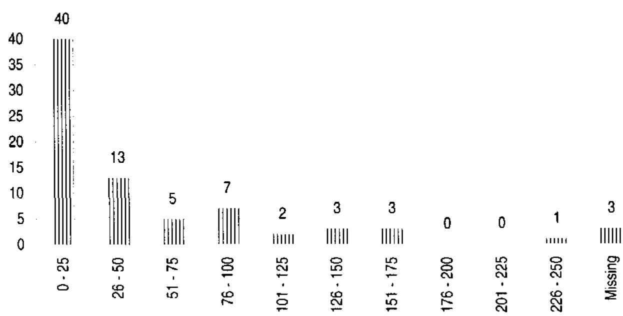


*Figure 5.12 Scores for DFE project score (DFE project score = m * Ag * Ag) of 77 companies*

The companies studied also differ considerably in terms of DFE result, indicated by their DFE project score. Figure 5.12 makes these differences even more clear. As many as forty companies have only a limited DFE project score of up to 25; these companies' DFE project scores are all within a narrow range. The DFE project scores of the remaining companies are considerably higher, ranging between 26 and 175. One company has an exceptionally high DFE project score of 250.

Does working with average success rates involve the risk of underestimated high success rates?

The question now is whether or not it is justified to measure the DFE score and DFE project score on the basis of the number of suggested options (n or m) and the average success rate (Rg or Ag). If a company has realized a limited number of DFE options from an extensive number of suggested DFE options, the average success rate is relatively low. This could result in a low DFE score, regardless of the fact that the company had realized various DFE options. The result would then be misleading in terms of the company's DFE result. If a company realizes various DFE options, it should also have a high DFE score.

To answer this we assessed the occurrence of high success rates (4, 5 or 6) among the participating companies. A correlation analysis was performed in order to find out how strong the link is between the variables 'DFE score' and 'occurrence of high success rates'. The scale of the variable 'occurrence of high success rates' ranged from 0 (none of the company's DFE options received a success rate higher than 0; the DFE score should be very low) to 18 (at least three of the company's DFE options received a success rate of 6; the DFE score should be very high).

The correlation analysis showed a strong correlation between DFE score and DFE project score and the occurrence of high success rates (Rp 0.77 respectively 0.84). This means that those companies that manifested high success rates, generally have a relatively high DFE score and DFE project score as well. We feared that companies could be given a low DFE score and DFE project score even if they had realized various DFE options. This could have been the case if a company had been suggested a large number of DFE options, and it had realized only a few. This fear proved to be groundless. As a result, measuring a company's DFE score and DFE project score on the basis of how many DFE options had been suggested (n or m), and the average success rate (Rg or Ag), would seem to be justified.

$n * Rg^2$ versus $n * Rg^3$

In the foregoing we suggested calculating a company's DFE by using the formula DFE score = $n * Rg^2$. Greater emphasis has been put on the factor 'Rg' intentionally than on the factor 'n' in this formula. But why not stress 'Rg' even more by applying the formula 'DFE score = $n * Rg^3$' ? In other words, does the adjusted formula 'DFE score = $n * Rg^2$' offer a more reliable scale to measure the DFE score than the formula 'DFE score = $n * Rg^3$'? In order to compare the two measurement scales a correlation analysis was carried out on the basis of empirical data. The two scales for measuring the DFE score were compared with the two other DFE result indicators: DFE design impact and DFE result opinion. Another factor they were compared with was the occurrence of high success rates. The correlation coefficients are listed in Figure 5.13. This led to the conclusion that all similarities between the formulas for DFE score and DFE project score and the DFE result indicators were slightly higher if the factors Rg or Ag are squared than if they are cubed. We will therefore keep to the formulas 'DFE score = n * Rg * Rg' and 'DFE project score = m * Ag * Ag' in this thesis.

	DFE score		**DFE project score**		**n**
	$n * Rg^2$	$n * Rg^3$	$m * Ag^2$	$m * Ag^3$	
DFE design impact	0,55	0,52	0,57	0,54	74
DFE result opinion	0,24	0,22	0,36	0,32	71
Occurrence of high success rates	0,77	0,70	0,62	0,56	74

Figure 5.13 Correlations of $n * Rg^2$ versus $n * Rg^3$ and three other DFE result indicators DFE design impact, DFE result opinion and 'occurrence of high success rates'

5.4.3 DFE design impact

What is the rate of occurrence of (major) product redesigns among the participating companies? It is assumed that the occurrence of a high direct DFE result is accompanied by a (major) product redesign. The IC EcoDesign project could result in a new product, an existing product's major or minor modification, packaging redesign, improved production processes or DFE oriented research. The extent of the product development is measured by a third DFE result indicator called DFE design impact.

As introduced in Chapter 3, there are ten categories of DFE design impact. These are listed in Figure 3.8 in Chapter 3. The extent of DFE design impact for each participating company was assessed by the author of this thesis who looked at how, and to what extent each DFE option suggested had actually been worked out into tangible product, packaging or process alterations. This information was then used as the basis upon which to define the design impact of the set of DFE options as a whole.

To illustrate the meaning of the various categories and the kind of environmental product improvements achieved, some examples of products 'new to the company', of 'major redesigns' and 'minor redesigns' are given below. These examples have been taken from this research project.

In the IC EcoDesign project two products were perceived as ***new to the company***:

- One product concerned an innovative, light-weight product to replace an existing packaging system;
- The second represented a change-over from the sale of products to the lease of products that had been radically redesigned to facilitate leasing.

A ***major redesign*** implies an alteration to the product's architecture. In the IC EcoDesign project a total of 21 companies manifested major redesigns. Examples are:

- Three companies integrated two products that had previously been manufactured separately and had had separate functions;
- Six companies reduced their product's weight by more than 25% (e.g. from 52 to 17 kg);
- Several companies completely redesigned their products to facilitate easy disassembly or modularity;
- Several companies radically redesigned their products in order to reduce the number of components (e.g. from 39 to 26 parts);
- One company achieved a 70% reduction in the amount of welding required for one of its products;
- Several companies selected alternative (mono-) materials to replace a hazardous material, implying a substantial redesign of the product and production processes (e.g. stainless steel to replace a copper/polyurethane compound; polypropylene injection moulding to replace a polyester sheet moulding compound).

A ***minor redesign*** is indicative of an improvement to product details within the framework of the existing architecture. Examples of minor redesigns resulting from the IC EcoDesign project are:

- The selection of alternative materials for parts of the product (e.g. polyethylene instead of PVC; polypropylene instead of ABS);
- A reduction in number of components from 25 to 20;
- A modest reduction in material use;
- The use of recycled material in a product component;
- The application of material codes to plastic components.

Figure 5.14 visualizes the scores of all 77 cases of this variable DFE design impact. It reveals a surprisingly high number of major product redesigns: the IC project had brought about a major product redesign in as many as 21 companies. We must acknowledge the fact that it would be unjustifiable to claim that these major redesigns were all exclusively due to the IC EcoDesign project. However, the estimation of the overall DFE design impact depended solely on the design impact of the set of DFE options suggested in the DFE action plan.

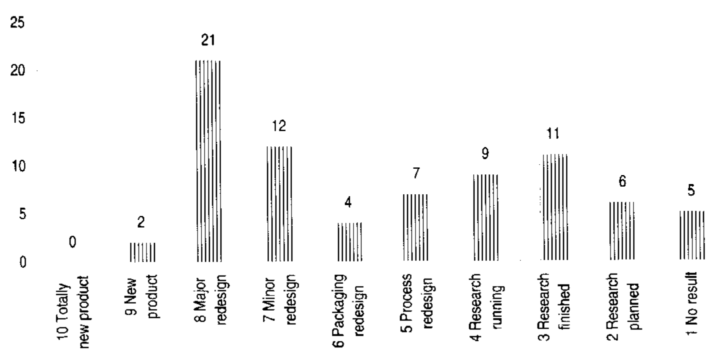


Figure 5.14 Scores for the DFE design impact in 77 companies

Figure 5.15 shows that in the 21 cases of major redesigns this DFE design impact can be attributed particularly to the impact of the set of DFE improvement options that the companies prioritized. Even though we did not measure the DFE result in quantitative and environmental terms for each company, the above findings indicate that considerable environmental product improvements were achieved in at least 21 companies.

5.4.4 DFE result opinion

The fourth and final indicator of the DFE result reflects the company's own opinion as to the effect of the IC EcoDesign project. This variable is called 'DFE result opinion' to emphasize its subjective character. In the written questionnaire the companies' representatives were asked how far they thought the IC EcoDesign project had resulted in 'concrete results' in their individual companies. The mark they could give ranged from 1 (no concrete results) to 5 (high concrete results). The answers given by the 77 companies are set out in Figure 5.15.

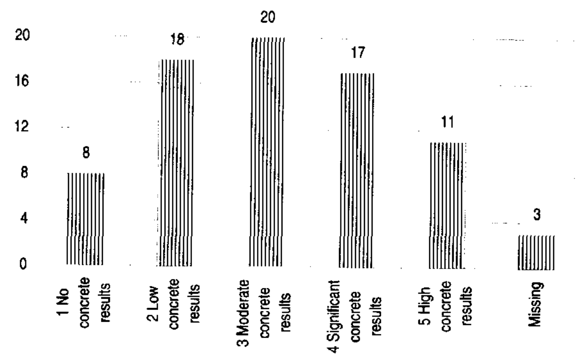


Figure 5.15 *Scores for DFE result opinion of 77 companies*

Figure 5.15 shows that, of the 74 companies that answered the question, 48 companies stated that the IC EcoDesign project had led to moderate to high concrete results. Only 8 of the 74 companies indicated that the project had not led to any concrete result at all. In addition, the respondents were asked to state their appreciation of the project by giving a mark ranging from 1 (very low level of appreciation) to 10 (very high level of appreciation). The average score was 7.0. Combining these findings we may conclude that there was a 'reasonably high' level of appreciation among the participating companies.

Figure 5.14, scores for DFE design impact, showed that for five companies the project yielded no results (as assessed by this thesis' author). Are these five companies among the eight which, according to Figure 5.15, scored very low for DFE result opinion? Analysis showed that the five companies scoring 'No result' for DFE design impact (category '1' in Figure 5.14) did indeed score very low on DFE result opinion (category '1' or '2' in Figure 5.15). And vice versa, the eight companies stating that the project had failed to lead to any concrete results scored a low mark with regard to DFE design impact as well. We may conclude that if the IC EcoDesign project led to few results, this was reflected in both variables, DFE design impact (reflecting the researcher's opinion), and DFE result opinion (reflecting the company's own opinion). Analysis showed that this was also true if the project had proved to be very successful. The eleven companies stating that the project had led to high concrete results (category '5' in Figure 5.15) also had very high scores for DFE design impact: with two exceptions only, the project had led to a 'major redesign' (category 8 in Figure 5.14). The opinions held by the researchers and the companies on the result of the IC EcoDesign project were more or less the same.

We may therefore conclude the following:

- *48 out of 74 companies stated that the IC EcoDesign project had yielded moderate to high concrete results. Only 8 stated that the project had not led to any concrete result at all. The companies' appreciation of the project was 'reasonably high'.*
- *The researcher's opinion on the results of the IC EcoDesign project corresponds with that of the company itself.*

5.4.5 Clustering the companies' scores in DFE result indicators

We obtain a good impression of a company's DFE result by looking at the four DFE result indicators: DFE score, DFE project score, DFE design impact and DFE result opinion. The scores of the companies investigated were presented in the sections above. We might expect that a company scoring well in one of these four indicators would also have scored well in the other three indicators for DFE result. Is this expectation justified? To answer this question a correlation analysis was performed by calculating the correlation coefficients between the four variables DFE score, DFE project score, DFE design impact and DFE result opinion. The analysis took all 77 cases into consideration.

All cases included	**DFE score**	**DFE project score**	**DFE design impact**	**DFE result opinion**
DFE score	--	--	--	--
DFE project score	0.81 n=74	--	--	--
DFE design impact	0.55 n=74	0.57 n=74	--	--
DFE result opinion	0.24 n=71	0.36 n=71	0.61 n=74	--

Figure 5.16 Correlation coefficients (Pearson's) between the four indicators for DFE result

Figure 5.16 shows that, as we expected, most of the correlation coefficients are considerably high. However, we see only a moderate correlation between DFE result opinion and DFE score (Rp 0.24), and between DFE result opinion and DFE project score (Rp 0.36). In some cases, a company's DFE result opinion appeared to be high, while its DFE score and DFE project score were relatively low, and vice versa. There are some companies with unexpected, inconsistent response patterns. How can this be explained? A cluster analysis was carried out to answer this question. The aim of this analysis was to identify clusters of companies with corresponding 'response patterns' for the four DFE result indicators.

Clustering companies according to response patterns

The cluster analysis resulted in the companies being grouped into ten clusters. Each cluster contains those companies that have similar response patterns for the four indicators DFE score, DFE project score, DFE design impact and DFE result opinion. The number of companies in a cluster varies quite substantially: some are composed of a large number of companies, while others consist of only one. The results of this cluster analysis are presented in Figure 5.17 below. This figure, however, needs some explanation.
First of all, each of the ten rows represent one cluster. Secondly, the columns DFE score, DFE project score, DFE design impact and DFE result opinion give the average scores for the companies that belong to that specific cluster. Thirdly, all clusters have been ranked from 1 to 10. This ranking was the result of comparing the clusters in terms of 'overall' DFE result (this was assessed by simultaneously balancing the scores for the four DFE result indicators).

Cluster	# companies	Cluster characterization	DFE score	DFE project score	DFE design impact	DFE result opinion
1	5	Very high DFE result	159	134	7.6	4.4
2	3	High DFE result	211	148	7.7	3.7
3	10	Good DFE result	107	83	7.4	3.6
4	3	Good DFE result (flattered)	111	19	7.7	3.7
5	1	Good DFE result (contradictory)	300	250	8.0	3.0
6	1	Good DFE result (contradictory)	192	65	7.0	2.0
7	19	Moderate DFE result	51	34	6.2	3.4
8	2	Moderate DFE result (dropped)	217	28	5.5	2.5
9	7	Low DFE result	68	12	4.4	2.7
10	20	Poor DFE result	11	7	3.6	2.5

Figure 5.17 *Results of the cluster analysis; exceptional clusters are 4, 5, 6 and 8 because of their inconsistent, contradictory response patterns*

Figure 5.17 shows that the three variables DFE project score, DFE design impact and DFE result opinion, are similar in terms of sequence, but do not match the DFE score sequence. The purpose of this ranking process as shown in Figure 5.17 was to show how much of a success the IC EcoDesign project had been for a specific company. In other words: this ranking stresses the contribution made by the three indicators DFE project score, DFE design impact and DFE result opinion, and thus reflects the project's added value. As a result, the final ranking of the clusters was based on the three variables DFE project score, DFE design impact and DFE result opinion, rather than DFE score.
For example: Figure 5.17 shows that DFE result cluster 2 has high scores for DFE project score and DFE design impact, but only has a score of 3.7 for DFE result opinion; this cluster is therefore characterized as 'High DFE result'. Cluster 1 has a relatively high score for these two indicators as well, plus a very high score for DFE result opinion (4.4). This cluster is consequently characterized as 'Very high DFE result'.

This cluster analysis revealed some inconsistencies in the companies' score profiles.
Cluster 4 consists of three companies with a ***'flattered'*** DFE result. The scores for DFE score, DFE design impact and DFE result opinion were considerably high; however, the DFE project score (the added value of the IC EcoDesign project) was unexpectedly low. Regardless of the obvious, low level of the IC project's added value, the companies still said they were positive about the outcome. While the individual representatives of these three companies probably thought very highly of the IC EcoDesign project, it had still failed to lead to many results in the individual companies.
Cluster 5, which is the opposite of cluster 4, consists of one company only. The scores for DFE score, DFE project score and DFE design impact are very high; the score for DFE result opinion is unexpectedly low. These ***'contradictory'*** scores are also present in cluster 6, showing the same type of inconsistency, although all the values are lower.
Finally, cluster 8 consists of two companies with an exceptionally high DFE score, combined with a DFE project score which is reduced by a factor 10, and low scores for DFE design impact and DFE result opinion. Since the results 'dropped' so radically cluster 8 is characterized as 'Moderate DFE result' with ***'dropped'*** outcomes. The four exceptional clusters 4, 5, 6 and 8 comprise a total of seven companies.

Exclusion of the seven exceptional cases

Clusters 4, 5, 6 and 8 comprise a total of seven companies with inconsistent score profiles for the four indicators DFE score, DFE project score, DFE design impact and DFE result opinion. We expect that, as presented in Figure 5.16, correlation between these four indicators will increase considerably if these seven companies are excluded from the analysis. Figure 5.18 shows the correlation coefficients between the four DFE result indicators if the seven exceptional cases are excluded.

Clusters 4-5-6-8 excluded	DFE score	DFE project score	DFE design impact	DFE result opinion
DFE score	--	--	--	--
DFE project score	0.91 n=67	--	--	--
DFE design impact	0.61 n=67	0.64 n=67	--	--
DFE result opinion	0.39 n=64	0.45 n=64	0.62 n=67	--

Figure 5.18 *Correlation coefficients (Pearson's r) between the four DFE result indicators if the seven exceptional cases of clusters 4, 5, 6 and 8 are excluded*

As we expected, if we now compare Figure 5.16 with Figure 5.18 we see an increase in all correlation coefficients; the coefficient between DFE result opinion and DFE score showing a particularly high increase. All the correlation coefficients between the DFE result indicators are now 'considerable' or 'high'.

The correlation coefficient between DFE score and DFE project score is 0.81 (Pearson's r) if all companies are included. If we exclude the exceptional cases, then we see an even stronger correlation between DFE score and DFE project score (Rp 0.91). The assumption is justified that companies with a high DFE score have a high DFE project score as well. The DFE score reflects the total number of DFE options suggested in a company's DFE action plan and the extent to which they were realized. While the DFE project score reflects the same, it excludes those DFE options the company would have considered regardless of the IC EcoDesign project (the options for which the project had a low level of added value). Since these two indicators are highly correlated we may conclude that generally speaking, companies that were already familiar with DFE at the start of the project, did not show a structurally higher or lower DFE result than those for which DFE was new.

We assumed that if a company has a high DFE score and a high DFE project score, this would be reflected in the company representative's opinion: correlation is expected between the DFE score and DFE project score on the one hand, and the DFE result opinion on the other. The figures above show that this is indeed the case. However, the level of correlation is not very high. If the exceptional cases are excluded the correlation coefficients increase from Rp 0.24 to Rp 0.39 (correlation with DFE score) and from Rp 0.36 to Rp 0.45 (correlation with DFE project score). These relatively moderate correlations can be explained by the fact that DFE score and DFE project score concentrate on the environmental improvements made to the actual product itself (while the company's representative might think highly of the project, thanks to any future spin-offs or other, less tangible results).

As expected, the correlation between DFE result opinion and DFE project score is much stronger than the correlation between DFE result opinion and DFE score. This can be explained by the fact that the DFE project score concerns the specific added value of the IC EcoDesign project.

Towards a single indicator for measuring a company's DFE result

The cluster analysis resulted in the ranking of ten clusters and thus a ranking of the overall DFE result of 71 of the 77 SMEs investigated. All four factors that indicate the DFE result (DFE score, DFE project score, DFE design impact and DFE result opinion) play a role in this ranking process. This implies that we had discovered a new scale for measuring the DFE result of a company as a whole. This scale for identifying a company's overall DFE result, ranging from 1 to 10, will be called the ***DFE result cluster scale***. Instead of working with four separate indicators, this single scale can be used in future bivariate statistical analyses carried out with the purpose of explaining why we see companies achieving different DFE results.

To verify the reliability of this DFE result cluster scale, a second DFE result scale was developed by means of Cronbach's α. This second scale will be called the **DFE result scale**. If there is a high degree of correlation between both scales for a company's overall DFE result, then we can conclude that we have indeed obtained a reliable scale for measuring the DFE result of the participants in the IC EcoDesign project.
Cronbach's α is meant to analyze whether the four indicators that make up DFE result can be combined into a single DFE result scale. The Cronbach's α for the four indicators DFE score, DFE project score, DFE design impact and DFE result opinion turned out to be 0.596 ($n = 71$). This meant that the four indicators could be standardized and then aggregated in order to create the DFE result scale. The Kolmogorov-Smirnov Goodness of Fit Test was applied to learn whether this DFE result scale had a spread that follows the 'normal curve'. The result of the test was normality was not rejected ($P = 0.61$, $n = 71$; P should be over 0.05).

Subsequently, we calculated the correlation between the DFE result cluster scale and the DFE result scale. With a correlation coefficient of 0.83 (Rp) these two scales for a company's overall DFE result turned out to have a high degree of correlation ($n = 71$). When we excluded the seven exceptional cases of the clusters 4, 5, 6 and 8, the correlation coefficient increased to 0.88 ($n = 64$). The conclusion is that either the DFE result cluster scale or the DFE result scale could be used for measuring a company's overall DFE result. Since a DFE result scale with 71 separate categories is more discriminating than a DFE result cluster scale with only 10 categories, and also because the DFE result scale permits the inclusion of the seven exceptional cases, it was decided to proceed with the DFE result scale.

The main conclusions of the statistical analyses presented in this section are:

- *The results of the cluster analysis (Figure 5.17) showed that it makes sense to group the companies into clusters, based on similarities in their response patterns. Each cluster in the '10 cluster typology of DFE result' represents a specific type of overall DFE result with regard to the IC EcoDesign project. The analysis emphasized the fact that a high DFE score is not always accompanied by a high DFE project score, a major DFE design impact* ***and*** *a high DFE result opinion.*
- *Furthermore, we found that a ranking based solely on DFE score gave a different picture than the ranking based on the combination of DFE project score, DFE design impact and DFE result opinion. The ranking according to Figure 5.17 specifically emphasizes DFE project score, DFE design impact and DFE result opinion at the cost of the indicator DFE score. This is because these three indicators are indicative of the success of the IC EcoDesign project for a specific company.*
- *Seven cases were identified which are exceptional due to the fact that they reveal remarkable inconsistencies in their response patterns with respect to the four DFE result indicators. Correlation between the four indicators for DFE result also increased considerably if these seven cases are excluded.*
- *Since DFE score and DFE project score have a high degree of correlation we may conclude that companies which were already familiar with DFE at the start of the project did not manifest a structurally higher or lower DFE result than those for which DFE was new.*
- *Finally, Cronbach's α showed that it was justified to aggregate the four DFE result indicators into a sole variable reflecting a company's overall DFE result: DFE result scale.*

5.5 Company DFE performance III: DFE learning

5.5.1 Introduction

The DFE performance of a company participating in the IC EcoDesign project was measured on the basis of three indicators: DFE focus, DFE result and DFE learning. After having focused on the DFE focus and the DFE result, we now shift our focus to the last DFE performance indicator, organizational learning with regard to DFE as a result of the IC EcoDesign project.

Chapter 3 described DFE learning as 'routines that enable and encourage a company to independently apply DFE in future product development projects'. To gain an impression of the DFE learning of a specific company, this study used nine indicators for measuring various aspects of DFE learning. Inspired by Van Berkel (1996), three levels of DFE learning were distinguished: the policy level, the organizational level and the operational level. The nine DFE learning indicators each relate to one of these three levels. The nine indicators, which reflect DFE learning, and their operationalization by a total of 47 variables, were presented in Figure 3.14 in Chapter 3.

In Section 5.4 we distinguished DFE improvement options from DFE actions. DFE actions do not relate directly to the product, the packaging or process design. Therefore they were excluded from further in-depth analysis. Instead, DFE actions concern managerial and organizational initiatives meant to analyze or reduce a company's environmental impact, regardless of the selected product. In a sense, the companies' DFE actions might provide an indication of their DFE learning. However, in order to analyze a company's organizational learning with regard to DFE, only the empirical data related to DFE learning were applied. One of the reasons for this being that DFE actions are only a subset of a company's DFE learning. Secondly, the DFE actions were only suggested incidentally by IC consultants. The companies' DFE learning was measured systematically by means of a pre-structured questionnaire (see Appendix B).

5.5.2 DFE learning as a result of the IC EcoDesign project

How much DFE learning did the participating companies achieve? As stated above, we can obtain an impression of a company's DFE learning by employing nine different DFE learning indicators. In Chapter 3, each indicator was operationalized by means of a set of 47 variables.
We will now present the scores achieved by the companies with regard to all the variables for measuring DFE learning as listed in Figure 3.14 in Chapter 3 and clustered into nine DFE learning indicators. The numbers just behind the variables' description refer to the questionnaire included in Appendix B.

Also presented is Cronbach's α for each of the nine DFE learning indicators. The aim was to reduce the number of variables by aggregating them into single indicators. Cronbach's α was calculated for each DFE learning indicator to see whether the variables could be aggregated into a new, single scale for the specific aspect of DFE learning. Only if Cronbach's α is 0.6 or higher can the variables in question be aggregated into a single indicator.

(1) DFE policy	**yes**	**no**	**irrelevant**	**n**
• Communication of DFE activities in the company annual report (160)	7	51	16	74
• Communication of DFE activities in the company corporate journal (161)	4	39	31	74
• Communication of DFE activities in other corporate publications (162)	10	36	28	74

As we expected, there are many cases in which companies stated that the question was 'irrelevant'. Far from all SMEs communicate by means of an annual report or a corporate journal. Only a few companies stated that they intended to communicate their DFE policy or initiatives by means of written, public documents. This could mean that companies doubt the usefulness or customer appreciation of communicating their DFE initiatives in public. Another factor is that the information could be too confidential. Furthermore, SMEs might feel insufficiently confident about their DFE initiatives to communicate them publicly.
The Cronbach's α of this set of three variables is 0.74 (n = 39). This means that the variables can be aggregated into one indicator for DFE policy.

(2) DFE objectives	**1** [1)]	**2**	**3**	**4**	**5**	**av.**[2)]	**irrel.**	**n**
• Environmental concerns in product planning procedures (163)	13	15	20	10	3	2.6	14	75
• Environmental concerns in product specifications (164)	13	15	24	10	3	2.6	10	75
• DFE budget when budgeting product development projects (165)	36	12	7	2	0	1.6	18	75
• Marketing DFE activities or new environmental product profile (154)	23	19	13	14	2	2.3	4	75

1) The scale ranges from 1 (never / not at all) to 5 (very often / to a high extent)
2) av. = the average score, 'irrelevant' cases are excluded

The DFE objectives indicator reflects the extent to which a company has internalized DFE principles into its own product development procedures. The figures show that a considerable number of SMEs

use product planning procedures. As many as 33 companies claim that they took environmental concerns into consideration 'occasionally' to 'very often' in their product planning procedures. Moreover, 37 companies said that they included environmental aspects in product specifications, ranging from 'occasionally' to 'very often'. However, these figures do not reveal the extent of these environmental concerns nor to which concerns the companies are referring.
Very few companies earmark a specific budget for DFE during product development. However, this is something which is unusual for smaller companies to do anyway. The number of SMEs that use DFE activities as a marketing instrument is limited. Various reasons that prevent companies from using DFE in their public communications are mentioned when discussing DFE policy. The Cronbach's α of this set of variables is 0.74 (n = 54); the variables can be aggregated into one indicator for DFE objectives.

(3) Integration of DFE in management system	yes	no	irrel.	n
• Assignment of DFE responsibilities to specific employees (170b)	45	29	--	74
• Incorporation of DFE in the company's Quality System (168)	22	33	19	74
• Incorporation of DFE in the company's Environmental Mgt. System (169)	19	25	30	74

The number of companies stating that they explicitly assigned DFE responsibilities to certain employees is remarkably high. This can partly be explained by the fact that a company automatically assigns DFE to the product development department since the subject relates to that department the most. It does not reveal the character of these responsibilities nor the amount of 'explicitness'.
The figures imply that as many as 55 companies have some sort of quality system, although not all of them are ISO certified. Also remarkably high is the number of companies claiming to incorporate DFE aspects in their quality system. Further research would reveal how this is done and the intensity.
There is a large number of companies that have an environmental management system (EMS) in place. These systems are both partial and integral systems; informal or certified. Many of the companies with some sort of EMS state that they will incorporate DFE into that system. We cannot tell in what sense these SMEs did or planned to do that. The figures do however reveal that the companies are not unwilling to establish a link between DFE and their EMS.
Cronbach's α of this set of three variables is 0.73 (n = 43). This means that the variables can be aggregated to one indicator for DFE management system integration.

(4) DFE internal involvement	yes	no	irrel.	n
• More than one employee participated in IC EcoDesign project (140b)	33	40	--	73
• IC Project was communicated at management level (143)	55	7	9	71
• IC Project was communicated with product developers (144)	42	5	21	68
• IC Project was communicated with marketing/sales department (145)	33	17	16	67
• IC Project was communicated with environmental manager (146)	10	12	39	62
• IC Project was communicated with quality manager (147)	20	14	28	64
• IC Project was communicated with purchasing department (148)	26	20	20	67
• IC Project was communicated with production department (149)	31	18	18	67
• IC Project was communicated with other department(s) (150)	11	18	31	60

The fourth DFE learning indicator, called DFE internal involvement, reflects how many other people in the company had been involved in, or informed about the IC EcoDesign project. This refers to how much the subject of DFE had been animated in a company. The figures show that only one person in more than half of the companies had participated in the project. This is hardly surprising: SMEs are known for their lack of time. The fact that in many cases the project was discussed at management level is not surprising either: in most cases the person involved in the project was the owner-manager. The subject was also often discussed with the product development department, the marketing/sales department and the production department.
It is quite remarkable to see that in only 10 out of 22 companies the person responsible for environmental issues was also involved in the IC EcoDesign project. We also see that 20 out of 34 quality managers were involved. This might be explained by the fact that by habit environmental managers focus on cleaning technology and cleaner technology; up to now they were generally

involved in production department work and hardly collaborated with product developers. Conversely, the activities pursued by quality managers relate more to product design. Cronbach's α of this total set of nine variables is 0.75 (n = 14). However, the number of companies that answered all nine questions was limited to 14. This means that it would be of little significance to aggregate the total set of variables to a single indicator. Therefore the variables 146 (only 22 answers), 147 (only 34 answers) and 150 (only 29 answers) were excluded. Cronbach's α of the limited set of six variables is 0.65 (n = 29). The six selected variables can be combined to one scale that measures the DFE internal involvement.

(5) DFE external involvement	**1 [1)]**	**2**	**3**	**4**	**5**	**av.**	**irrel.**	**n**
• Cooperation on DFE within the supply chain (vertical) (122)	22	21	13	12	4	2.1	--	72
• Cooperation on DFE within the industry (horizontal) (123)	40	21	9	0	2	1.7	--	72
• Cooperation on DFE with knowledge institutes (124)	20	21	17	6	8	2.5	--	72
• Discussion of DFE issues with customers (155)	5	17	21	23	7	3.1	2	75
• Discussion of DFE issues with recyclers/disposers (157)	20	13	17	11	9	2.7	5	75

1) The scale ranges from 1 (never / not at all) to 5 (very often / to a high extent)

The indicator, DFE external *involvement, reflects the extent to which a company has cooperated with,* in respect of DFE, or has involved any outside parties. Although there were a few exceptions, the SMEs studied rarely cooperated with other companies in the product supply chain (vertical), and even to a lesser extent with other companies in their own branch of industry (horizontal). Somewhat higher is the score for cooperation with knowledge institutes. It is commonplace for the companies studied to discuss matters relating to DFE on a regular basis with customers and to a lesser extent with recyclers. It is hardly surprising to see that the average scores for these 'cooperation' variables are low in comparison with the 'discussion' variables: cooperation, in terms of DFE, is more obligatory and pro-active than discussion.
Cronbach's α of this set of variables is also 0.68 (n = 67). The variables can be aggregated into a single indicator for DFE external involvement.

(6) DFE awareness	**1 [1)]**	**2**	**3**	**4**	**5**	**av.**	**n**
• Knowledge on DFE in general (115)	1	12	20	23	18	3.6	74
• Knowledge on the environmental aspects of the materials used (116)	1	15	11	34	13	3.6	74
• Knowledge on the environmental profile of the product's life cycle (117)	5	14	15	25	15	3.4	74
• Knowledge on product-oriented environm. legislation/regulation (118)	9	19	23	21	2	2.8	74
• Being prepared for the impending take-back legislation (119)	19	23	18	12	2	2.4	74
• Being able to apply DFE independently in future product developm. (120)	6	10	29	20	8	2.8	73

1) The scale ranges from 1 (never / not at all) to 5 (very often / to a high extent)

A company's DFE awareness indicates how much the knowledge has been increased; this relates to knowledge of DFE in general and to specific DFE subjects. Particularly high average scores were achieved for DFE knowledge in general, for knowledge about the environmental aspects of the materials used, and for knowledge on the environmental problems that crop up during the products' life cycle.
The lowest scores in the table above refer to the extent to which the companies have prepared themselves for take-back legislation. As many as 60 companies state to be prepared 'not at all' or 'slightly'. This could indicate that as long as regulation is not yet in force, SMEs - with obvious exceptions - will not prepare their product, or their organization, for take-back.
Cronbach's α of this set of six variables is 0.79 (n = 72). This means that the variables can be aggregated to one indicator for DFE awareness.

(7) DFE follow-up activities	yes	no	irrel.	n
• Feasibility study of some suggested DFE improvement options (126)	21	52	--	73
• Cost accounting of the suggested DFE improvement options (132)	28	31	9	68
• DFE principles already applied to another product (130)	26	32	11	69
• DFE principles will be applied to other product(s) (131)	47	8	14	69
• Search for DFE-related information after the intervention (133)	19	44	5	68
• Application of DFE-related software after the intervention (134)	3	61	4	68
• Participation in DFE meetings after the intervention (135)	12	49	7	68
• Expectation to follow DFE training (137)	15	38	13	66
• Another DFE-related follow-up activity (138)	11	30	5	46

The indicator, DFE follow-up activities, reflects the extent to which a company has applied or plans to apply DFE principles in future product development activities. The first variable is somewhat misleading. The expression 'feasibility study' refers to the second phase of the IC EcoDesign project: companies were able to obtain support for studying the feasibility of some of the DFE options suggested. This support was provided from outside, generally through the mediation of a consultancy. Only 21 of the 73 companies that answered this question had actually made use of this opportunity. The other 52 companies had not asked for any external support which had been made possible by the IC EcoDesign project. In many cases, they conducted a feasibility study on some DFE options without the help of external support. This is reflected by the following variable which refers to the cost of the suggested DFE options; 14 companies that had no assistance from outside calculated the costs involved in realizing certain DFE options. This can be seen as a initial feasibility study.
It was quite remarkable to see that companies had often already applied DFE principles to products other than the one involved in the Environmental Innovation Scan. Even more positive are the scores in respect of the companies' plans to apply DFE principles in future product development. Very few of the SMEs studied had applied specific DFE-related software after the intervention: only 3 out of 68. This emphasizes that, generally speaking, SMEs are not particularly fond of using software tools for DFE.
Cronbach's α for this set of nine variables was 0.59 (n = 24). This means that a new scale could be set up for DFE follow-up activities, but that the values of only 24 companies were known. This somewhat limited number is due to variables 137 and 138 which combine a low response rate with mostly negative scores. They have a low discriminatory value and do not match the other variables. Therefore the variables 137 and 138 were omitted from the selection. The Cronbach's α of the remaining seven variables increases to 0.60 (n = 46). This means that the variables can be aggregated to a new scale that measures the DFE follow-up activities of 46 companies.

(8) DFE specification	1 [1]	2	3	4	5	av.	irrel.	n
• Specification of DFE concerns in procurement procedures (151)	15	20	24	6	3	2.4	6	74
• Specification of DFE concerns when outsourcing production (152)	17	20	19	3	2	2.2	13	74
• Specification of DFE concerns when outsourcing development (153)	12	12	19	3	4	2.5	23	73
• Specification of DFE concerns in cost estimates for customers (156)	29	16	17	5	5	2.2	3	75

1) The scale ranges from 1 (never / not at all) to 5 (very often / to a high extent)

The eighth indicator for DFE learning was called DFE specification; this indicates the extent to which DFE issues are specified with regard to procurement, outsourcing and cost estimates. The scores for the four variables, adding up to become the DFE specification are, apart from of five to ten exceptions, quite low. If we compare all four situations, DFE requirements are specified the most explicitly when outsourcing product development.
Cronbach's α of this set of three variables is 0.87 (n = 48). However, variable 153 has a low response rate: 23 companies said that the question was irrelevant since they did not often outsource product development. If this variable is omitted, the number of companies scaled on the DFE specification scale increases from 48 to 61 with a Cronbach's α of 0.85. Therefore the variables 151, 152 and 156 can be aggregated to one indicator for DFE specification.

(9) DFE protocol	yes	no	irrel.	n
• Requires suppliers to sign a non-toxicity declaration (158)	7	63	4	74
• Requires suppliers to sign a take-back obligation (159)	11	57	6	74
• Development of a company-specific DFE manual (166)	3	62	10	75
• Development of a company-specific DFE checklist (167)	17	45	13	75

The last DFE learning indicator represents the extent to which a company has developed written procedures to ensure the application of DFE in future purchasing and development. A total of 7 out of 70 companies asked suppliers to sign a non-toxicity declaration; 11 out of 57 companies placed a supplier under the obligation to guarantee the take-back of their products. Taking into account that the companies studied are SMEs, these results are not disappointing. However, the figures do not reveal the kind of measures that have been taken, the number of suppliers involved, etc.
As expected, many more companies have developed a company-specific DFE checklist than a company-specific DFE manual. As many as 17 companies developed some sort of DFE checklist and 3 companies developed a DFE manual. Details on these documents and how they are used can be generated by means of further in-depth study.
Cronbach's α of this set of four variables is 0.42 (n = 56). Since the α is lower than 0.6 the resulting scale after the variables have been summed up would be unreliable. However, factor analysis showed that the four variables could be integrated into one factor. This single factor could be taken as the scale that measures the DFE protocol of 56 companies. The analysis showed that the DFE protocol factor is mainly based on variable 167 (DFE checklist). This is positive since the development of a DFE checklist is regarded as a meaningful element of a DFE protocol.

In summary, the companies investigated achieved the following DFE learning:

- *DFE policy: only a few companies stated that they intend to communicate their DFE policy or initiatives by means of written, public documents;*
- *DFE objectives: as many as 33 companies claim they apply environmental aspects 'occasionally' to 'very often' in their product planning procedures. Moreover, 37 companies said they integrated environmental concerns in their in-house product specifications; this ranged from 'occasionally' to 'very often'.*
- *DFE management system integration: many companies stated that they explicitly assigned DFE responsibilities to certain employees. A remarkably high number of companies stated the incorporation of DFE aspects in their quality system. Many companies with a (generally informal) EMS said that they wished to create a link between DFE and their EMS.*
- *DFE internal involvement: while it was usual for only one person to participate in the project, in many cases the project was discussed at management level; it was discussed 'relatively often' with in-house product developers, the marketing/sales department and the production department. The persons responsible for environmental issues were not always involved in the project, probably because they had always focused on production matters. Quality managers were somewhat more frequently involved, probably because their activities relate more directly to product design.*
- *DFE external involvement: most SMEs rarely cooperated with other companies in the product supply chain, and even to a lesser extent within their own branch of industry. Slightly higher are the scores for cooperating with knowledge institutes. The companies discuss DFE issues more often with customers than with recyclers.*
- *DFE awareness: particularly high are the average scores for DFE knowledge in general, for knowledge about environmental aspects of the materials used, and for knowledge on the environmental problems that crop up during the products' life cycle. Only very few companies are prepared to take back their products.*
- *DFE follow-up activities: only 21 companies made use of the opportunity to obtain assistance from an external consultancy regarding feasibility studies of suggested DFE options. In addition, 14 companies which had did not requested support from outside sources stated that they had calculated the costs of DFE options; this can be seen as a initial feasibility study. It became evident that companies had often already applied DFE principles to other products. Many companies planned to apply DFE principles in future product development. Very few SMEs had applied specific DFE-related software, indicating that SMEs are not particularly fond of applying software tools for DFE.*
- *DFE specification: apart from certain exceptions, the companies studied hardly specify any DFE aspects in their procurement procedures when outsourcing production or development, or in customer cost estimates. DFE requirements are specified most explicitly when outsourcing product development and in procurement.*
- *DFE protocol: as many as 17 companies developed some sort of DFE checklist, and 3 developed a DFE manual. Only 7 out of 70 companies asked a supplier to sign a declaration of non-toxicity; 11 out of 57*

companies place suppliers under the obligation to take back their products. For SMEs these results are certainly not disappointing.

- *The level of company DFE learning was the* **highest** *with regard to the following aspects: DFE objectives (integrating DFE in in-house product planning procedures), DFE management system integration (especially the linking of DFE to existing EMS or QS), DFE internal involvement (involvement of management and product developers), DFE awareness (increase of DFE-related knowledge), DFE follow-up activities (with particular regard to applying the newly acquired DFE experience to other products) and DFE protocol (especially in terms of using a DFE checklist).*
- *The companies' DFE learning was* **low** *in terms of DFE policy (the companies hardly communicated DFE initiatives in public documents), DFE external involvement (the companies hardly cooperated with external parties in terms of DFE) and DFE specification (companies hardly specified DFE requirements for external parties).*
- *The empirical findings presented here do not reveal the various aspects of DFE learning (like DFE checklists, follow-up activities) or how intensively they are applied in the development practices of SMEs. These would be interesting subjects for future study.*

5.5.3 Selecting a set of indicators for DFE learning

The above section presented the companies' scores with regard to DFE learning, the last of three DFE performance indicators. Nine DFE learning indicators were operationalized by a set of variables and used to gain an understanding of the extent of organizational learning in terms of DFE in the companies studied.
We wish to shift our focus in a later stage from describing the companies' DFE learning to explaining it: can we explain why certain companies perform better than others in terms of DFE (now: DFE learning)? This question will be answered by means of statistical bivariate correlation analyses. However, working with as many as nine DFE learning indicators as dependent variables is not very practical. We therefore decided to select four DFE learning indicators out of the total set of nine.

The first criterion for selection was the number of cases represented by a specific indicator. The four selected DFE learning indicators each contained the measurements of at least 48 companies. This made them useful for statistical analysis. The second criterion was the discriminatory value of the variable. The four selected indicators originate from variables with scales ranging from 1 to 5 and therefore are more discriminating, and also have a higher explanatory value than the other variables that originate from dichotomous scales. The four DFE learning indicators that were selected, and their meanings, are presented in Figure 5.19 below.

DFE learning indicator	Meaning of the indicator
DFE objectives	The extent to which a company has internalized DFE in its product development procedures by setting objectives
DFE external involvement	The extent to which a company cooperated or became involved with outside parties on DFE
DFE awareness	The extent to which a company increased its knowledge in terms of DFE in general and of specific DFE subjects
DFE specification	The extent to which DFE subjects are specified with regard to procurement, outsourcing and customer estimates

Figure 5.19 The four selected DFE learning indicators and their meanings

Relation between the four DFE learning indicators

The expectation is that if a company scores high for one DFE learning indicator, it will have relatively high scores for the other three as well. In other words, we expect the four selected indicators for DFE learning to be correlated to some extent. A correlation analysis was performed in order to check this assumption. The results are given in Figure 5.20 below.

		DFE objectives	DFE ext. involv.	DFE awareness	DFE specification
DFE learning indicators	DFE objectives	--	--	--	--
	DFE external involvement	0.51 (n=50)	--	--	--
	DFE awareness	0.28 (n=51)	0.30 (n=66)	--	--
	DFE specification	0.83 (n=39)	0.62 (n=47)	0.36 (n=46)	--

Figure 5.20 The mutual correlation (Pearson's r) between the four DFE learning indicators

Figure 5.20 shows the mutual correlation between the four indicators for DFE learning, ranging from 'considerable' (Rp 0.28) to 'very high' (Rp 0.83). These correlations among the four selected DFE learning indicators suggest that they can be aggregated into a single DFE learning scale.
To analyze whether the resulting scale would be reliable, Cronbach's α was calculated. Cronbach's α of 0.81 (n=37) showed that the four scales could indeed be aggregated into a single DFE learning scale.

Thanks to the clustering of 47 variables into nine DFE learning indicators and a subsequent selection of four of these, a company's DFE learning can be expressed by one single variable: the **DFE learning scale**. The newly calculated DFE learning scale ranges from -2.0 to +3.0 and includes the overall DFE learning of a limited number of 37 companies. Figure 5.21 is included so as to give an impression of the distribution of the companies' overall DFE learning. This figure presents the number of companies in the specific categories of the DFE learning scale. The scale, ranging from -2.0 to +3.0, was divided into ten categories. Figure 5.21 illustrates that the DFE learning in most companies is concentrated in the range between -1.5 and +1.5. Three companies have an exceptionally high level of overall DFE learning; one company lagged behind.

DFE learning scale	-2.0 ~ -1.5	-1.5 ~ -1.0	-1.0 ~ -0.5	-0.5 ~ 0.0	0.0 ~ 0.5	0.5 ~ 1.0	1.0 ~ 1.5	1.5 ~ 2.0	2.0 ~ 2.5	2.5 ~ 3.0
Number of companies	1	5	6	10	4	5	3	1	1	1

Figure 5.21 Distribution of the companies' scores in the newly calculated DFE learning scale (n=37)

The conclusions of this section are:
- *Initially, a company's DFE learning was measured on the basis of 47 variables, encompassed in nine DFE learning indicators. Statistical analysis of the empirical data showed that these variables could be aggregated into nine separate DFE learning indicators.*
- *Subsequently, from these nine DFE learning indicators, four were selected. Further statistical analysis showed that these four indicators could be combined, resulting in a company's DFE learning can now be expressed by a single variable: the DFE learning scale.*
- *As we assumed, there is a considerable difference regarding the overall DFE learning achieved by the various companies.*

5.6 Relation between DFE focus, DFE result and DFE learning

5.6.1 Introduction

The preceding sections focused on the three DFE performance indicators DFE focus, DFE result and DFE learning. In the following section the relation between these three indicators will be assessed in order to reflect upon hypothesis 2 as introduced in Chapter 4. Hypothesis 2 was:

Hypothesis 2.A Companies that manifest a good DFE result, as a result of the IC EcoDesign project, will also achieve a high level of DFE learning.

Hypothesis 2.B Companies that manifest a good DFE result and a high level of DFE learning as a result of the IC EcoDesign project also have a comparable DFE focus.

Section 5.6.2 sets out the results of the analysis of the relationship between DFE result and DFE learning and reflects upon hypothesis 2.A. Subsequently, Section 5.6.3 reflects upon hypothesis 2.B by exploring the relationship between DFE result, DFE learning and the eight DFE focus clusters.

5.6.2 Reflection on hypothesis 2.A

So far we have assumed that companies with a high level of DFE learning will also have a high DFE result. This means that companies manifesting high scores for the four selected indicators for DFE learning will also achieve a high score for the DFE result indicators: the DFE result indicators are correlated with the four selected DFE learning indicators. A correlation analysis was performed in order to find out the extent to which the DFE result and DFE learning (as manifested by the companies participating in the IC EcoDesign project) were correlated. The results of this analysis are presented in Figure 5.22.

	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE Result Scale
DFE objectives		0.16 (53)	0.33 (54)	0.14 (53)	0.17 (52)
DFE external involv.		0.29 (66)	0.28 (67)	0.42 (66)	0.36 (65)
DFE awareness	0.12 (70)	0.27 (70)	0.34 (72)	0.56 (71)	0.40 (69)
DFE specification		0.21 (46)	0.34 (48)	0.18 (47)	0.21 (45)
DFE Learning Scale		0.25 (37)	0.40 (37)	0.43 (36)	0.35 (36)

Figure 5.22 Correlations between the four DFE result indicators and the DFE result scale, and the four DFE learning indicators and DFE learning scale (Pearson's r; only correlations above 0.10 are given; the number of cases is in brackets)

If the correlation coefficient is below 0.25 then the variables are said to be 'weakly' correlated. Variables are 'considerably' correlated if the coefficient is between 0.25 and 0.65, and correlation coefficients higher than 0.65 indicate that the variables are 'strongly' correlated.

According to Figure 5.22, the correlation between the four indicators for DFE learning and the DFE result indicators range from 'very low' (Rp 0.03; not shown in the figure) to 'considerable' (Rp 0.56). The DFE project score, DFE design impact and DFE result opinion have a higher correlation with the indicators for DFE learning than for DFE score. This is in line with our findings that DFE project score, DFE design impact and DFE result opinion reflect the actual benefits and success of the IC EcoDesign project in a company much better than DFE score. It is not surprising that companies for which the added value of the IC EcoDesign project was high (as stressed by the DFE project score) also show a relatively high score for DFE learning indicators.

Also relatively high is the correlation between DFE result opinion and DFE external involvement (Rp 0.42) and DFE awareness (Rp 0.56). This indicates that companies appreciated the outcomes of the IC EcoDesign project if it had provided them with new information on the subject of DFE (increase of DFE awareness) and if the companies had increased the amount of cooperation in terms of DFE with outside parties (an increase in the amount of DFE external involvement). This could also imply that, when asked to express an opinion about the 'concrete results' they had achieved by virtue of the IC EcoDesign projects, these companies not only looked at the tangible product improvements but also at certain intangible aspects of DFE learning.

The empirical findings apparently support hypothesis 2.A: companies manifesting a high DFE result will indeed achieve relatively high scores for DFE learning as well. Most DFE result indicators and DFE learning indicators are mutually correlated, albeit to widely differing extents; the correlation coefficients range from Rp 0.03 to Rp 0.56.

The DFE project score, DFE design impact and DFE result opinion correlate more strongly with the DFE learning indicators than with DFE score. This is line with our findings that DFE project score, DFE design impact and DFE result opinion reflect the actual benefits and success of the IC EcoDesign project in a company better than DFE score.
There is a relatively high degree of correlation between DFE result opinion and DFE external involvement and DFE awareness. This indicates that companies appreciated the outcomes of the IC EcoDesign project if it had provided them with new DFE-related information and if they increased the amount of cooperation in terms of DFE with outside parties.

.6.3 Reflection on hypothesis 2.B

Hypothesis 2.B represents the assumption that companies manifesting a high DFE result and a high degree of DFE learning as a result of the IC EcoDesign project share a comparable DFE focus. To analyze whether this assumption is supported by empirical data this section looks at the relation between the companies' DFE focus on the one hand, and their DFE result and DFE learning on the other.
In section 5.3 we described how the 60 companies (out of the 77 studied) that prioritized one or more DFE improvement options (by attributing them with a success rate of 4, 5 or 6) were categorized in eight so-called 'DFE focus clusters' in accordance with the type and number of DFE improvements options they had prioritized. The question that now needs answering is: Do the companies in the specific DFE focus clusters correspond in terms of their extent of DFE result and DFE learning?

A correlation analysis was carried out to find out whether companies with high DFE results and DFE learning belong to certain DFE focus clusters. The indicators for DFE result and DFE learning are all variables at the ordinal level. Conversely, the variable 'DFE focus cluster' is a nominal variable. Therefore not the Pearson's or Spearman's coefficient should be applied, but the contingency coefficient. The number of cases should be sufficiently high to ensure a Minimum Expected Frequency of more than 1 (calculated by the Chi-Square). However, the Minimum Expected Frequency proved to be lower than 1 in all calculations. This means that the contingency coefficient was not the correct correlation indicator. The solution was found by applying the eta (η) as the indicator for correlation. Figure 5.23 presents the results of the correlation analysis.

	DFE result					DFE learning				
	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE result scale	DFE objec-tives	DFE external involv.	DFE aware-ness	DFE specifi-cation	DFE learning scale
DFE focus cluster	0.61 (60)	0.51 (60)	0.29 (60)	0.26 (58)	0.49 (58)	0.41 (47)	0.40 (56)	0.27 (57)	0.38 (38)	0.41 (33)

Figure 5.23 The correlation coefficients (_) between the nominal variable DFE focus cluster and the ordinal DFE result and DFE learning indicators (the number of cases is given in brackets)

Figure 5.23 shows that the correlation between the various indicators for DFE result and the DFE focus cluster are considerably high (η ranging from 0.26 to 0.61). Moreover, the DFE focus cluster and the various indicators for DFE learning are also correlated to a large extent (η ranging from 0.26 to 0.41). As we assumed, the eight DFE focus clusters not only differ in the DFE focus the companies had prioritized, but in the DFE result and DFE learning of the companies as well.

The relatively high correlations found with DFE score (η 0.61) and with DFE project score (η 0.51) are hardly surprising since to a limited extent these variables are interdependent. The classification of companies into eight DFE focus clusters was based on the type and number of prioritized DFE improvement options. Yet there are some significant differences. Although the variables ‚DFE score and DFE project score, partly depend on the **number** of DFE improvement options, the DFE score and the DFE project score were calculated without considering the **type** of options. Furthermore, DFE focus clustering was based on the prioritized DFE improvement options only (success rates 4, 5 or 6), although the two variables, DFE score and DFE project score, include DFE improvement options with success rates 1, 2 and 3 as well. Because of these differences the variables DFE focus cluster, DFE score and DFE project score, are treated as independent.

The empirical findings would seem to support hypothesis 2.B. As assumed, correlation analysis shows that companies with relatively high scores for DFE result indicators and DFE learning indicators are concentrated in specific DFE focus clusters. In other words, we find empirical support for the assumption that companies sharing a specific DFE focus, also share a similar DFE result and DFE learning.

This conclusion leads to the following intriguing question. Can we identify DFE focus clusters consisting of companies with high level of DFE results and DFE learning, as opposed to DFE focus clusters consisting of less successful companies?
Scatter plots were made in order to identify which DFE focus clusters are particularly related to high scores for DFE result and DFE learning indicators. By analyzing these scatter plots, which shows the DFE focus cluster number on the X-axis and the various indicators for DFE result or DFE learning on the Y-axis, the actual character of the various DFE focus clusters was somewhat easier to comprehend. However, detailed conclusions about the scores for DFE learning and DFE result in specific DFE focus clusters proved to be unjustified. One of the main reasons for this being that five out of eight clusters contained only a very small number of companies. Moreover, since not all companies answered each question, there is only a limited amount of data remaining on which to base conclusions as to the character of these five clusters. This implies that we can identify differences in DFE result and DFE learning between the eight DFE focus clusters, but we do not know whether these differences are representative of the entire cluster. All of this implies that we cannot provide a satisfactory answer to the intriguing question mentioned above. More detailed conclusion can be drawn if, in future research, we study a larger sample of companies.

Stimuli and barriers for design for environment

Chapter 6 focuses on research question A: How can we explain the difference in success among the 33 DFE principles distinguished? First the stimuli and barriers are presented brought forward by the SMEs studied for the group of DFE options as a whole. This is followed by a discussion of the stimuli and barriers identified at the level of the individual DFE principles. After describing the stimuli and barriers mentioned by the companies, an analysis is made of the influence these stimuli and barriers have on the success rates of the DFE options as a whole and on each of the 33 DFE principles. This paves the way to reflect on hypotheses 1.A, 1.B and 1.C.

Introduction

Chapter 5 made it very clear that preference, regarding specific success rates, is given to some of the 33 DFE principles than to others. Is there an explanation as to why certain DFE principles achieve a higher success rate than others? The first objective of this research is to find an answer to this question. The assumption is that this differences in success rate can be explained by both the stimuli and barriers regarding each DFE principle as perceived by the companies concerned. Using the literature on environmental management in industry (in both large and small businesses) certain assumptions were formulated and included in research model A. This model is visualized in Figure 6.1.

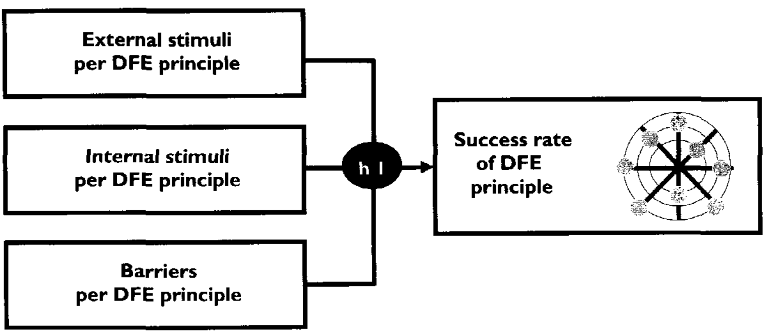


Figure 6.1 *Research model A with hypothesis 1, consisting of sub-hypotheses 1.A, 1.B and 1.C*

Research model A, formulated in Chapter 4, will be elaborated in Chapter 6 by means of the empirical research data gathered during the monitoring research component of the IC EcoDesign project. The core of research model A is hypothesis 1, broken down into the following hypotheses 1.A, 1.B and 1.C:

Hypothesis 1.A: *Regarding the application of DFE in small and medium-sized enterprises, the actual influence of internal stimuli on the success rate of DFE principles is stronger than the influence of external stimuli.*

Hypothesis 1.B: *Of all the internal stimuli that motivate a small company to implement DFE improvements, the personal environmental commitment of that company's owner-manager is the most influential factor.*

Hypothesis 1.C: *The companies participating in the DFE EcoDesign project will reject suggested DFE improvement options subjected to the barriers 'insufficient complementarity', 'lack of interesting technological options' and 'insufficient appropriability'*

These hypotheses are tested in this chapter. Section 6.2.1 presents the stimuli and barriers the companies brought forward for the group of DFE options as a whole. A total of 596 so-called DFE improvement options had been suggested in the DFE action plans for the group of 77 SMEs.

This is followed by a discussion of the stimuli and barriers identified at the level of the individual DFE principles in Section 6.2.2. This study distinguished a total of 33 different DFE principles, clustered into eight DFE strategies. After describing the stimuli and barriers mentioned by the 77 SMEs interviewed, an analysis will be made of the influence these stimuli and barriers have on the success rates of the DFE options. The focus is first on the influence of the stimuli and barriers on the group of suggested DFE improvement options as a whole (Section 6.3.1). Their influence on the success rates of each of the 33 DFE principles is subsequently identified in Section 6.4, paving the way to reflect on hypotheses 1.A, 1.B and 1.C and answer research question A in Section 6.5.

6.2 Stimuli and barriers

The group of SMEs interviewed had been suggested a total of 596 DFE improvement options. The question is why certain DFE improvement options (characterized according to a typology of 33 DFE principles) obtain higher success rates than others. In an effort to answer this question, an assessment of those factors that motivate or, conversely, demotivate the implementation of each DFE improvement option was performed. During interviews over the telephone the representatives of these companies were asked to state which stimuli and barriers they perceived for each DFE improvement option suggested. The questionnaire that was used for this interview was pre-structured and listed three categories: external stimuli, internal stimuli and barriers (see Appendix A). These three categories were formulated in Chapter 4 on the basis of a literature survey on environmental management. The following sections present the empirical findings.

6.2.1 Stimuli and barriers regarding the DFE options in general

External stimuli

Let us first concentrate on the external stimuli for the DFE improvement options, as perceived by the companies. For each suggested DFE improvement option the interviewer read out the total set of potential external stimuli (as listed in Figure 6.2) one by one. The interview results, in terms of the number of external stimuli and their typification, are listed in Figure 6.2.

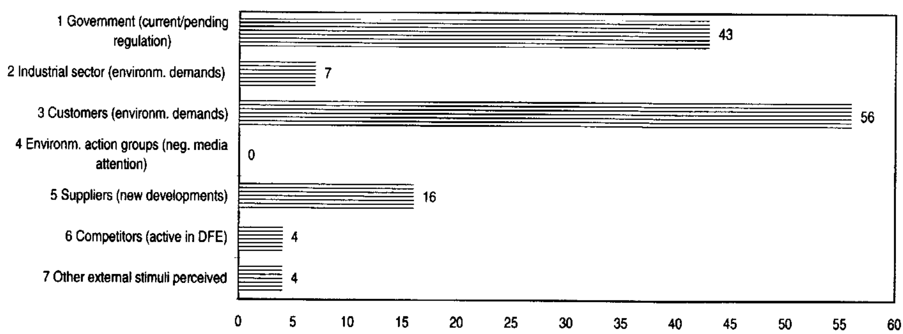


Figure 6.2 External stimuli perceived by the SMEs for all DFE improvement options (130 external stimuli were given for a total of 111 of the 596 options)

Figure 6.2 leads us to draw the following conclusions:

- For only 111 of the 596 options one or more external stimuli were given; this means that no external stimuli were mentioned for 485 options (81 %).
- The total number of external stimuli mentioned is limited to 130. More than one external stimulus was mentioned for only 17 of the 596 DFE options; the maximum number of external stimuli mentioned for one DFE improvement option was three.

Figure 6.2 also shows that the 'top three' external stimuli concern:

- 'Customers' (mentioned 56 times),
- 'Governmental regulation' (43 times) and
- 'Suppliers' (16 times).

If we take the number of times these factors were mentioned as being indicative of a factor's importance, then the influence of 'customer demands' is evidently somewhat stronger than 'government regulation'. This contradicts the literature on environmental management which states that government regulation is a predominant factor, even regarding DFE (e.g. Green et al., 1994). It confirms our assumption that the influence of regulation may be strong in theory, but it seems to be limited in business practice. In terms of number of times they were mentioned, the external stimuli 'Industrial sector' and 'Competitors' seem to have very little influence; the external stimulus 'Environmental action groups' seems to have no significance at all.

The above conclusions must be treated with care since we must be aware that the frequency at which a factor is mentioned is only an indication of its actual influence. Nevertheless, we wish to draw some additional conclusions. The influence of the product supply chain (on the part of both customers and suppliers) seems to be relatively strong, reflecting the traditional pressure of these partners on product development in SMEs. The influence exerted by the relevant branch of industry and the competitors seems to be limited; this can be explained by the fact that the amount of interest shown by the SME sector for DFE was always very low. The fact that environmental action groups do not exert any external pressure on SMEs to introduce DFE is not surprising either since these groups usually focus attention on larger companies with eye-catching, high environmental impact activities.

Internal stimuli

A distinction was made in advance between external and internal stimuli for DFE. The external drivers discussed above originate from outside the company; the internal stimuli originate directly from inside the company and concern the company's owner-manager's *personal commitment* to the environment and various commercial values relating to DFE. The number and types of internal stimuli mentioned by the companies' respondents during the telephone interviews are given in Figure 6.3.

For each suggested DFE improvement option the interviewer went through the total set of potential internal stimuli (as listed in Figure 6.3) one by one, with the exception of 'Environmental benefit'. The interviewer only recorded this stimulus if it was mentioned spontaneously. This was to prevent insinuations and thus reduce the 'window-dressing' effect related to this specific stimulus. The other stimuli were thought to be less liable to window-dressing. Therefore, the interviewer suggested them in turn for each DFE option.

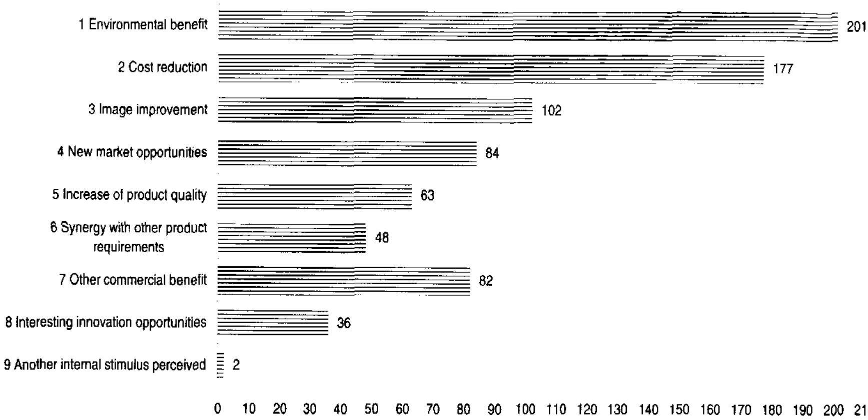


Figure 6.3 *Internal stimuli mentioned for all DFE improvement options (a total of 795 internal stimuli were mentioned for 339 of the 596 options)*

Figure 6.3 leads to the following conclusions:

- The respondents mentioned at least one internal stimulus for 339 of the 596 DFE improvement options; the number of DFE options for which no internal stimulus was mentioned was consequently 257 (38%). This was 81% for the external stimuli.
- The total number of internal stimuli mentioned was 795. This is more than six times the number of external stimuli (130). The maximum number of internal stimuli mentioned for one DFE option was as high as 8; two or more internal stimuli were given for 219 DFE options.

Furthermore, the 'top three' internal stimuli were:

- 'Environmental benefit' (mentioned 201 times),
- 'Cost reduction' (177 times) and
- 'Image improvement' (102 times).

These were followed by 'New market opportunities' (84 times) and 'Other commercial benefit' (82 times).

In contrast to the other internal stimuli, the stimulus of 'Environmental benefit' was not prompted by the interviewer but was only recorded if mentioned spontaneously. The fact that 'Environmental benefit' was mentioned as a stimulus in 201 DFE options reveals that this factor has an influence on decision-making in companies (even though we can only make a guess as to its actual impact). The many times 'Cost reduction', 'Image improvement', 'New market opportunities', 'Increase of product quality', 'Synergy with other product requirements', 'Other commercial benefit' and 'Interesting innovation opportunities' were stated as internal stimuli confirms the often heard statement that DFE might have interesting commercial side-effects. 'Cost reduction' in particular is such a commercial benefit the companies investigated regarded as an internal stimulus.

Barriers

It was not only the stimuli that were asked for, but also the barriers that stand in the way of realizing the suggested DFE improvement options. During the interview the interviewer read out the pre-defined list of potential barriers (see Figure 6.4) for each of the suggested DFE improvement options. The number of barriers and the specific type of barriers stated by the company representatives are visualized in Figure 6.4.

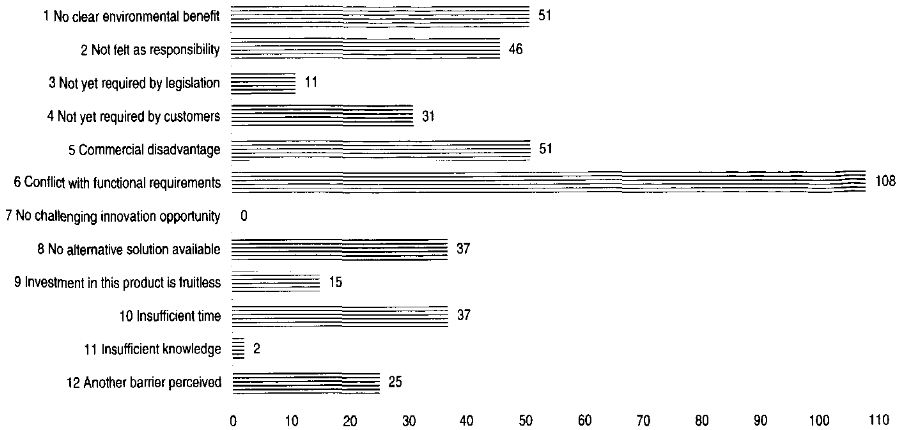


Figure 6.4 *Barriers for all DFE improvement options; a total of 414 barriers were mentioned for 322 of the 596 options*

Figure 6.4 clearly shows that the companies studied distinguish quite a few barriers for the DFE improvement options suggested to them:

- One or more barriers were mentioned for 322 of the 596 DFE options; this implies that no barriers were perceived for 274 of the 596 options (46%).
  Does this mean that all the options with no barriers were prioritized? As we will see later, the answer to this question is no. Stimuli, external or internal, seem to be the main prerequisites.
- The total number of barriers perceived was 414. The company's representative perceived two or more barriers in the case of 80 DFE options. The maximum number of barriers mentioned was three.

Figure 6.4 shows that the top three barriers were:

- 'Conflict with functional requirements' (mentioned 108 times),
- 'No clear environmental benefit' (51 times) and
- 'Commercial disadvantage' (51 times).

These three were followed by 'Not our responsibility' (46 times), 'No alternative available' (37 times), 'Insufficient capacity in time' (37 times) and 'Not yet required by customers' (31 times).

Remarkably high was the frequency at which the barrier 'Conflict with functional requirements' was mentioned. However, we will see later on that this type of barrier is only an 'initial' barrier, meaning that we find many DFE improvement options that were prioritized, regardless of this type of barrier mentioned. The respondents also stated their doubts as to the actual environmental benefit of 51 of the 596 suggested DFE improvement options (9%). The following Section 6.2.2 explains the type of DFE option to which this applies in particular.

If we take the number of times a barrier was mentioned as being indicative of its influence, the barrier 'Not yet required by customers' (mentioned 31 times) seems to have more influence than 'Not yet required by legislation' (11 times). These figures again lead us to presume that the SMEs studied perceive environmental customer demands as a more important driver for DFE than governmental legislation. Furthermore, it reflects the special character of DFE in comparison with other elements of environmental management: customers may be more concerned about changes in the final product design than about changes in the company's production processes or environmental management system. However, the effect could also be due to the special characteristics that apply to most SMEs (identified as 'reactive'), the customer demands having a strong influence on the decisions they take.

The reactiveness of most companies could also explain the high frequency of the barriers 'Not our responsibility' (46 times) and 'No alternative available' (37 times). The respondents sometimes stated that DFE did not fit in with 'their strategy'. When asked the reason for this, they generally said that they did not regard DFE as their responsibility. The respondents also often mentioned that they see their companies as not being influential enough to bring about any changes without the help of larger companies. Moreover, their companies did not wish to invest in the development of alternatives for the current environmental problems because of the perceived risks involved with such developments. SMEs generally think that larger companies should take the lead in risky development investments. Remarkably low was the frequency of the barrier 'Insufficient knowledge' in working out the suggested DFE improvement options. A lack of knowledge was evidently not a major problem for the SMEs studied. This is hardly surprising since the SMEs participating in the IC EcoDesign project had obtained a great deal of support from their IC consultants, including specific DFE-related knowledge.

To summarize the empirical findings described above, Figure 6.5 presents an overview. Note that this figure lists only the most frequently mentioned stimuli and barriers. Whether they are also the most influential ones will be analyzed in Section 6.3.

	External stimuli	Internal stimuli	Barriers
Total number	130	795	414
For how many of the 596 DFE options?	111 (19%)	339 (62%)	322 (54%)
Which stimuli/barriers were the most frequently mentioned?	1. Customer demands (56) 2. Government regulation (43) 3. Supplier developments (16)	1. Environmental benefit (201) 2. Cost reduction (177) 3. Image improvement (102)	1. Conflict with functional requirem. (108) 2. No clear environmental benefit (51) 3. Commercial disadvantage (51)

Figure 6.5 *Overview of the number of stimuli/barriers mentioned, the number of DFE options involved and the top three types of stimulus/barrier, in accordance with the number of times they were mentioned*

Figure 6.5 shows the number of external stimuli that were mentioned (130 for a total of 111 DFE options) and the number of internal stimuli (795 for a total of 339 DFE options). It is essential here that we keep in mind that the frequency with which a stimulus/barrier is mentioned no more than indicates how much influence these factors have. Moreover, the list of external stimuli in the questionnaire covered six stimuli; the list of internal stimuli, eight. However, taking this into account, the differences are still remarkable. They lead us to draw a preliminary conclusion that, in the SMEs studied, internal stimuli are a stronger driving force for DFE than external stimuli. This result does not correspond with the theory currently exists which decrees that external drivers are the most influential for enhancing the environmental initiatives in industry. Section 6.3 analyzes the influence of the specific external and internal stimuli on the success rates of the DFE improvement options (in other words: their chance of becoming prioritized).

6.2.2 Stimuli and barriers mentioned per DFE principle

Up to now we have presented and discussed the stimuli and barriers mentioned by the SMEs for the total group of 596 DFE options. In the following we will proceed with our presentation of these stimuli and barriers, but now with a focus on the type of DFE option to which they relate. Chapter 2 introduced the typology of eight DFE strategies in 34 categories (33 'DFE principles' plus a separate category called 'DFE actions') which was applied in the research project reported on in this thesis. All 596 DFE improvement options suggested to the SMEs in 1995 are typified according to this typology. This enables us to distinguish the stimuli and barriers mentioned for each of the 33 DFE principles. The stimuli and barriers are presented in the bar charts shown in Figure 6.6, Figure 6.7 and Figure 6.8. The next three sections subsequently go into more detail on the external stimuli, the internal stimuli and the barriers mentioned for the 596 DFE options.

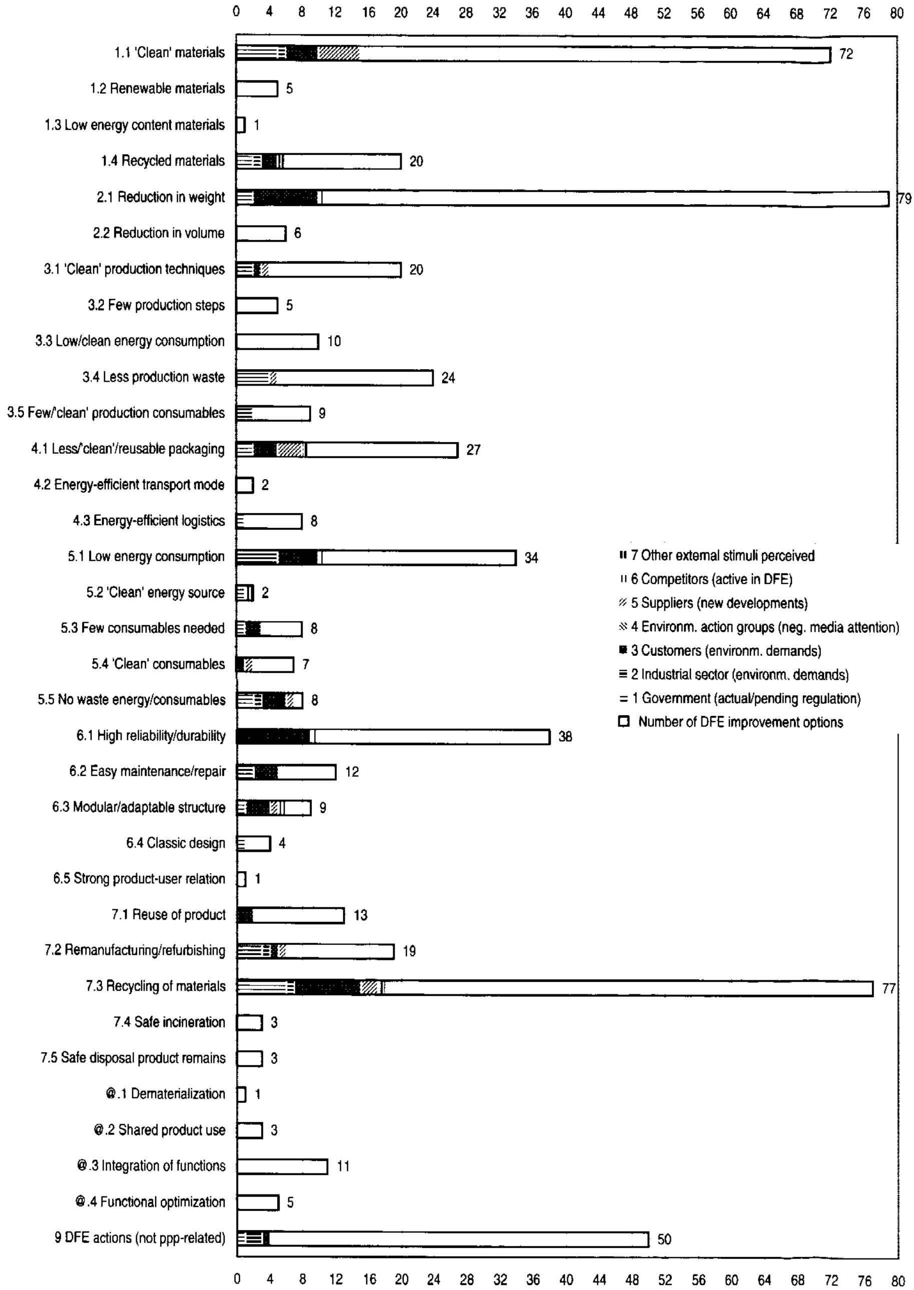


Figure 6.6 *The external stimuli mentioned (130 in total) for all 596 suggested DFE options, categorized according to the typology of DFE principles, and stacked according to the type of stimulus*

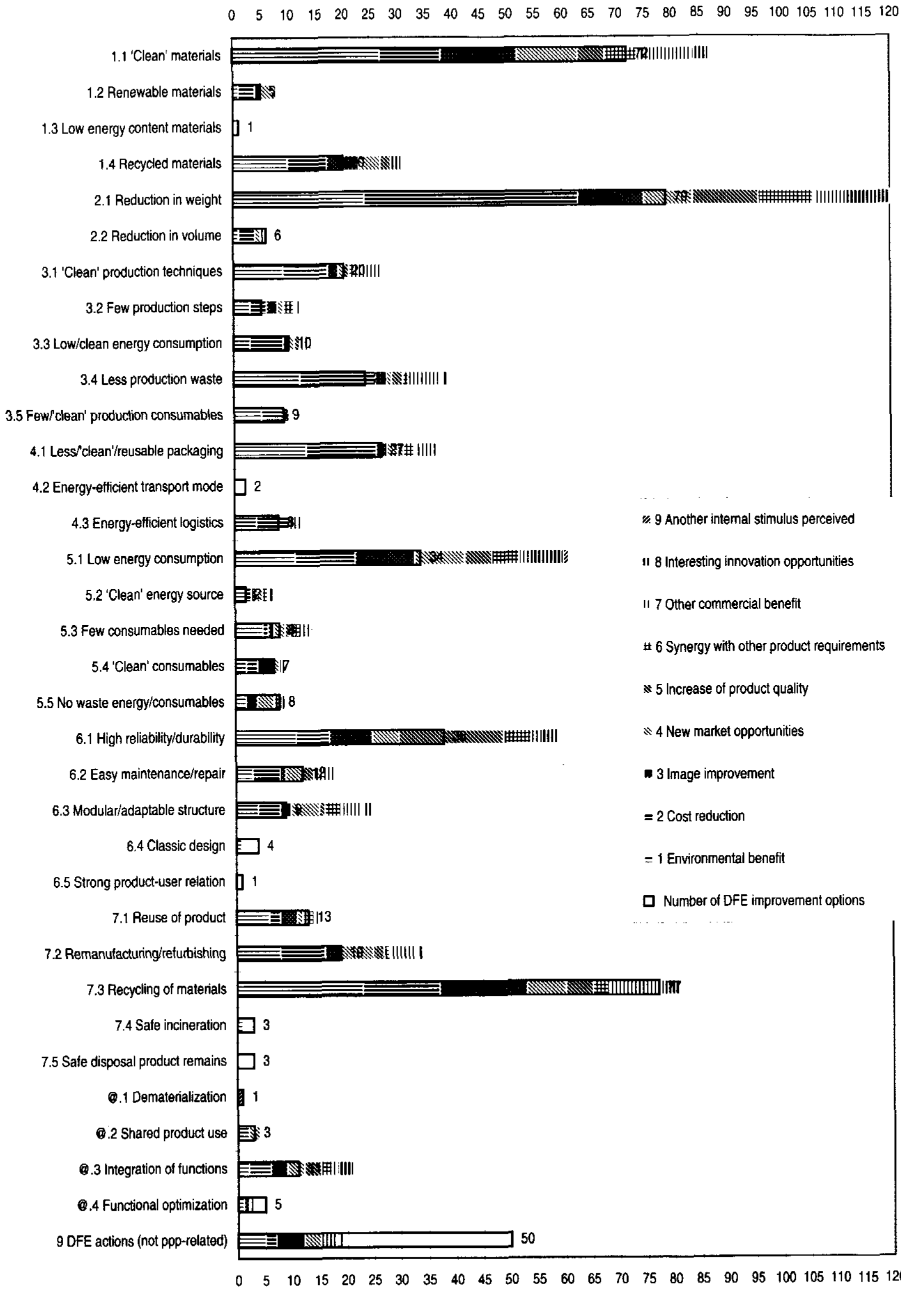


Figure 6.7 *Internal stimuli mentioned (795 in total) for all 596 suggested DFE options, categorized according to the typology of DFE principles, and stacked according to the type of stimulus*

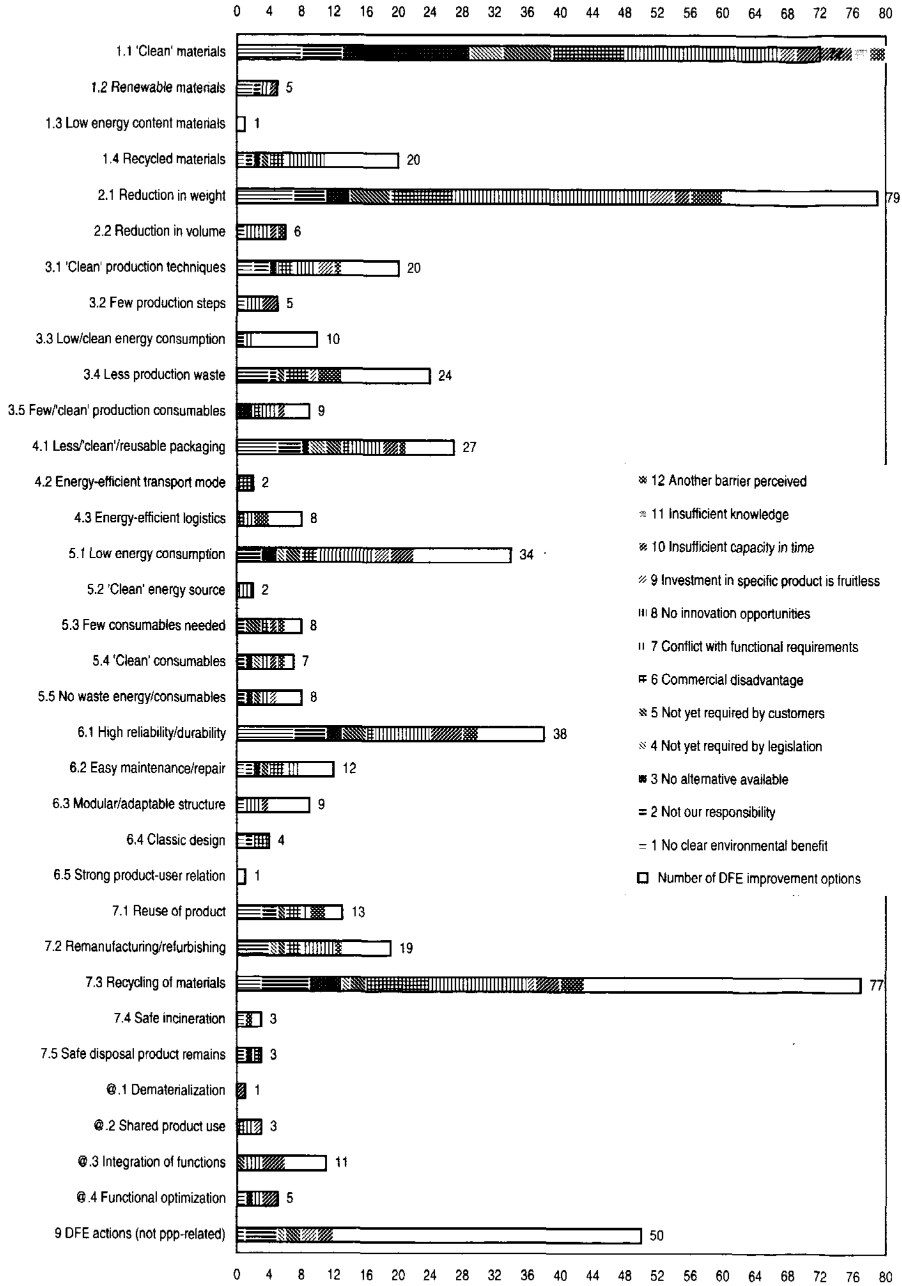


Figure 6.8 *Barriers mentioned (414 in total) for all 596 suggested DFE options, categorized according to the typology of DFE principles, and stacked according to the type of stimulus*

6.2.3 External stimuli per DFE principle

The bar chart presented in Figure 6.6 shows that a total of 130 external stimuli were mentioned for 111 (out of 596) DFE improvement options. Each type of stimulus is marked separately with a different pattern. The number of suggested DFE options per DFE principle is printed to the right of each bar in the chart, presented graphically in the form of empty bars. For example: 72 DFE options were suggested for DFE principle 1.1 'Selection of clean materials'. For this specific DFE principle the companies interviewed had mentioned a total of 15 external stimuli of the types 'Governmental regulation', 'Industrial sector', 'Customers', and 'Suppliers'. These 15 stimuli were mentioned for only 13 out of the 72 options of this type of DFE principle.

If we look at the absolute numbers of external stimuli in the chart we see that many external stimuli ***in absolute terms*** were mentioned for the following DFE principles:

- 1.1 'Selection of clean materials' (15 stimuli for 13 of 72 DFE options of this type of DFE principle),
- 2.1 'Reduction in weight' (11 stimuli for 11 of 79 options),
- 4.1 'Less/clean/reusable packaging' (9 stimuli for 9 of 27 options),
- 5.1 'Low energy consumption' (11 stimuli for 9 of 34 options),
- 6.1 'High reliability/durability' (10 stimuli for 10 of 38 options) and
- 7.3 'Recycling of materials' (18 stimuli for 16 of 77 options).

For most of these DFE principles it would seem that three different types of external stimuli are important; government legislation and customer demand being the most dominant. However, as many as four different types of external stimuli were mentioned often with regard to Selection of clean materials and Recycling of materials. As expected, the highest number of stimuli in absolute terms were mentioned for those types of DFE principle that were represented the most. However, in order to learn which external stimuli are relatively important for individual DFE principles, we should concentrate on the relative frequency of stimuli per DFE principle.

Let us then look at those DFE principles that received many external stimuli ***in relative terms*** in comparison with the number of DFE options of that type of DFE principle. External stimuli were generally mentioned for 25% of the DFE options of a specific type of DFE principle. However, some DFE principles were attributed with a relatively higher number of stimuli. This was the case for:

- 4.1 'Less/clean/reusable packaging' (9 stimuli for 9 of 27 options),
- 5.1 'Low energy consumption' (11 stimuli for 9 of 34 options),
- 5.5 'No waste of energy/consumables' (7 stimuli for 4 of 8 options),
- 6.2 'Easy maintenance/repair' (5 stimuli for 5 of 12 options) and
- 6.3 'Modular/adaptable product structure' (6 stimuli for 3 of 9 options).

The relative figures imply that the companies studied perceived a relatively large number of external stimuli for these five DFE principles. The bar chart presented in Figure 6.6 shows that for these DFE principles the dominant types of external stimuli are government regulation and customer demand. The only exception is Modular/adaptable product structure, which would not seem to be stimulated by government legislation but by competitors' initiatives. Only in the case of Less/clean/reusable packaging, do suppliers' activities seem to exert an influence as well. Furthermore, the initiatives of competitors are apparently important drivers only in the case of Low energy consumption and Modular/adaptable product structure.

The companies studied perceived no external stimuli at all for 13 DFE principles. External stimuli are lacking in particular for DFE strategy New concept development, represented by the DFE principles @.1 'Dematerialization', @.2 'Shared product use', @.3 'Integration of functions' and @.4 'Functional optimization'.

If we take the number of times external stimuli were mentioned as an indication of how great an influence they are, then we may conclude that government regulation is the most influential for DFE principles:

- 1.1 'Selection of clean materials',
- 3.4 'Less production waste',
- 5.1 'Low energy consumption' and
- 7.3 'Recycling of materials'.

The industrial sector is a driver only in case of DFE principles:
- 1.1 'Selection of clean materials' and 1.4 'Recycled materials',
- 5.5 'No waste of energy/consumables',
- 7.2 'Remanufacturing/refurbishing' and 7.3 'Recycling of materials'.

The environmental customer demands are most relevant for the DFE principles:
- 1.1 'Selection of clean materials',
- 2.1 'Reduction in weight',
- 5.1 'Low energy consumption',
- 6.1 'High reliability/durability' and
- 7.3 'Recycling of materials'.

Suppliers' developments are influential with respect to the DFE principles:
- 1.1 'Selection of clean materials',
- 4.1 'Less/clean/reusable packaging' and
- 7.3 'Recycling of materials'.

Finally, the companies' competitors are seen as drivers only for the following DFE principles:
- 2.1 'Reduction in weight',
- 5.1 'Low energy consumption',
- 6.1 'High reliability and durability' and 6.3 'Modular/adaptable product structure'.

Surprisingly, environmental action groups are never perceived as a driving force towards any DFE principle.

To conclude, the findings on external stimuli are summarized in Figure 6.9. This figure presents the findings on those DFE principles that attracted many external stimuli, in absolute as well as relative terms. Furthermore, the figure also presents the fields of influence of each external stimulus.

In conclusion, the empirical findings on external stimuli per DFE principle are as follows:
- *In absolute terms, the highest number of external stimuli mentioned by the respondents concerned six specific DFE principles. In relative terms many external stimuli were mentioned for five DFE principles. Only for 'packaging' and 'low energy consumption in the use phase' were many external stimuli mentioned in absolute as well as relative terms.*
- *'Government legislation' and 'customers' demands' are the most frequently mentioned external stimuli. There are, however, two exceptions here. These concern 'high product reliability/durability' and 'modular/adaptable product structure' which are driven by customer demands and the initiatives of competitors, rather than government legislation.*
- *As many as four different types of external stimuli were often mentioned for 'selection of clean materials' and 'recycling of materials'.*
- *External stimuli were lacking especially in the case of DFE strategy @ 'New concept development'.*
- *The companies studied did not perceive the activities of environmental action groups as a driver for DFE.*

DFE strategies and principles	many ES(abs)	many ES(rel)	ES 1 gov.	ES 2 ind.	ES 3 cust.	ES 4 act.	ES 5 sup.	ES 6 com.
1 Selection of low-impact materials								
1.1 Clean materials	■		✔	✔	✔		✔	
1.2 Renewable materials								
1.3 *Low energy content materials*								
1.4 Recycled materials			✔	✔				
2 Reduction of materials usage								
2.1 Reduction in weight	■		✔		✔			✔
2.2 Reduction in volume								
3 Optimization of production techniques								
3.1 Clean production techniques			✔					
3.2 Fewer production steps								
3.3 Low/clean production energy								
3.4 Less production waste			✔					
3.5 Few/clean production consumables			✔					
4 Optimization of distribution system								
4.1 Less/clean/reusable packaging	■	■	✔		✔		✔	
4.2 Energy-efficient transport mode								
4.3 Energy-efficient logistics								
5 Reduction of impact during use								
5.1 Low energy consumption	■	■	✔		✔			✔
5.2 Clean energy source								
5.3 Few consumables needed					✔			
5.4 Clean consumables								
5.5 No waste of energy/consumables		■	✔	✔	✔			
6 Optimization of initial lifetime								
6.1 High reliability and durability	■				✔			✔
6.2 Easy maintenance and repair		■	✔		✔			
6.3 Modular /adaptable product structure		■			✔			✔
6.4 Classic design								
6.5 Strong product-user relation								
7 Optimization of end-of-life system								
7.1 Reuse of product					✔			
7.2 Remanufacturing/ refurbishing			✔	✔				
7.3 Recycling of materials	■		✔	✔	✔		✔	
7.4 Safe incineration (energy recovery)								
7.5 Safe disposal of product remains								
@ New concept development								
@.1 Dematerialization								
@.2 Shared product use								
@.3 Integration of functions								
@.4 Functional optimization								

■: The DFE principle was motivated by a significant number of external stimuli

✔: This external stimulus was mentioned at least twice for the DFE principle in question (once in the case of a scarce type of stimulus)

Figure 6.9 *Overview of the findings concerning the external stimuli per DFE principle (in absolute and relative terms) and the specific fields of influence of the types of external stimuli*

6.2.4 Internal stimuli per DFE principle

So far we have discussed the external stimuli for DFE improvement options categorized according to their DFE principles. Next, the bar chart in Figure 6.7 presented the internal stimuli for the DFE improvement options, as mentioned by the company representatives. In this figure the internal stimuli are categorized according to the type of DFE principle and stacked according to the type of stimuli. The total number of internal stimuli was 795; all of which were mentioned in connection with 322 of the 596 suggested DFE options.

Most internal stimuli ***in absolute numbers*** were mentioned for the DFE principles:
- 1.1 'Selection of clean materials',
- 2.1 'Reduction in weight',
- 5.1 'Low energy consumption',
- 6.1 'High reliability and durability' and
- 7.3 'Recycling of materials',

followed by 1.4 'Recycled materials', 3.4 'Less production waste', 4.1 'Less/clean/reusable packaging' and 7.2 'Remanufacturing/refurbishing'. As also applied in the case of external stimuli, the high frequency at which these stimuli were mentioned was probably because of their strong connection with the high number of DFE options belonging to the specific DFE principles.

We will now concentrate on the ***relative numbers***, being the numbers of internal stimuli compared to the numbers of DFE options of a certain type of DFE principle. Some DFE principles show a higher than average number of internal stimuli. The average is two stimuli for each of about half the DFE options of a specific type of DFE principle. We find that many internal stimuli in relative terms are perceived for the following DFE principles:
- 2.1 'Reduction in weight' (120 stimuli for 48 of 79 options),
- 3.2 'Fewer production steps' (12 stimuli for 4 of 5 options) and
- 3.4 'Less production waste' (39 stimuli for 17 of 24 options),
- 5.2 'Clean energy source' (7 stimuli for 2 of 2 options),
- 6.1 'High reliability and durability' (59 stimuli for 22 of 38 options),
- 6.3 'Modular/adaptable product structure' (25 stimuli for 6 of 9 options) and
- @.3 'Integration of functions' (21 stimuli for 6 of 11 options).

While the relative number of internal stimuli is somewhat lower, it is still significant regarding DFE principles 1.2 'Renewable materials', 1.4 'Recycled materials', 3.1 'Clean production techniques', 3.3 'Low/clean production energy' , 4.1 'Less/clean/reusable packaging', 4.3 'Energy-efficient logistics', 5.1 'Low energy consumption', 5.3 'Few consumables needed', 5.5 'No waste of energy/consumables', 6.2 'Easy maintenance and repair', 7.1 'Reuse of product' and 7.2 'Remanufacturing/refurbishing'. For the DFE principles @.1 'Dematerialization', @.2 'Shared product use', @.3 'Integration of functions' and @.4 'Functional optimization' (which together form DFE strategy 'New Concept Development), a total of 29 internal stimuli was mentioned. This contrasts with the amount of external stimuli for this strategy, being zero.
In the case of six DFE principles, the companies studied perceived no internal stimuli at all. This concerned the DFE principles 1.3 'Low energy content materials', 4.2 'Energy-efficient transport mode', 6.4 'Classic design', 6.5 'Strong product-user relation', 7.4 'Safe incineration' and 7.5 'Safe disposal of product remains'. This can be partly explained by the limited number of DFE options suggested for these types of DFE principle.

If we take the frequency at which these internal stimuli were mentioned as being indicative of their influence, we see a mix of internal stimuli for almost all DFE principles. The 'Environmental benefit' was a relevant stimulus for many of the DFE principles. This also applies with regard to 'Cost reduction'.
'Image improvement' was somewhat less omnipresent, being mostly connected with the DFE principles:
- 1.1 'Selection of clean materials' and 1.4 'Recycled materials',
- 2.1 'Reduction in weight',
- 5.1 'Low energy consumption',
- 6.1 'High reliability and durability' and
- 7.3 'Recycling of materials'.

The companies studied expected 'New market opportunities', especially in the case of DFE principles:
- 1.1 'Selection of clean materials' and 1.4 'Recycled materials',
- 2.1 'Reduction in weight',
- 4.1 'Less/clean/reusable packaging',
- 5.1 'Low energy consumption' and 5.5 'No waste of energy/consumables',
- 6.1 'High reliability and durability' and 6.3 'Modular/adaptable product structure',

- 7.2 'Remanufacturing/refurbishing' and 7.3 'Recycling of materials'.

An 'Increase in product quality' was often perceived in the case of DFE principles:

- 1.1 'Selection of clean materials',
- 2.1 'Reduction in weight',
- 5.1 'Low energy consumption',
- 6.1 'High reliability and durability' (very often),
- 7.3 'Recycling of materials', and
- @.3 'Integration of functions'.

'Synergy with other product requirements' was mainly expected in case of DFE principles:

- 1.1 'Selection of clean materials',
- 2.1 'Reduction in weight',
- 3.2 'Fewer production steps',
- 5.1 'Low energy consumption',
- 6.1 'High reliability and durability' and 6.3 'Modular/adaptable product structure',
- 7.1 'Reuse of product', 7.3 'Recycling of materials' and
- @.3 'Integration of functions'.

'Other commercial benefits' were perceived for options with DFE principles:

- 1.1 'Selection of clean materials',
- 2.1 'Reduction in weight',
- 3.1 'Clean production techniques' and 3.4 'Less production waste',
- 4.1 'Less/clean/reusable packaging',
- 6.2 'Easy maintenance and repair' and 6.3 'Modular/adaptable product structure',
- 7.2 'Remanufacturing/refurbishing' and 7.3 'Recycling of materials'.

Finally 'Interesting innovation opportunities' were expected mainly in relation to DFE principles:

- 2.1 'Reduction in weight',
- 5.1 'Low energy consumption',
- 6.1 'High reliability and durability' and 6.3 'Modular/adaptable product structure' and
- @.3 'Integration of functions'.

In conclusion, Figure 6.10 summarizes the findings about the internal stimuli mentioned above. The figure indicates for which DFE principle many external stimuli were mentioned, in absolute as well as in relative terms. Furthermore, the figure shows to what extent the various internal stimuli were relevant for each DFE principle.

The main empirical findings on the internal stimuli for each DFE principle are:

- *In absolute terms, most internal stimuli were mentioned for nine DFE principles in particular, distributed over DFE strategies 1 to 7. In relative terms, most internal stimuli were attributed to seven DFE principles. Many internal stimuli were mentioned in both absolute and relative terms for three DFE principles only: 'reduction in weight', 'less production waste' and 'high reliability/durability'.*
- *In the case of six DFE principles, the companies studied perceived no internal stimuli at all.*
- *For six DFE principles, as many as seven or eight different types of internal stimuli were mentioned quite frequently. These DFE principles are distributed over six different DFE strategies and include DFE principle @.3 'Integration of functions'.*
- *Various internal stimuli were mentioned for DFE strategy @ 'New concept development'. Especially DFE principle @.3 'Integration of functions' was attributed with a large number of internal stimuli of seven different types. There were no external stimuli for this DFE strategy.*
- *The 'Environmental benefit' and 'Cost reduction' were relevant internal stimuli for many different DFE principles.*
- *No internal stimuli were mentioned in connection with six DFE principles. These were 'low energy content materials', 'energy-efficient transport mode', 'classic design', 'strong product-user relation', 'safe incineration' and 'safe disposal of product remains'.*

DFE strategies and principles	many ES(abs)	many ES(rel)	IS 1 envi.	IS 2 cost.	IS 3 image	IS 4 mark.	IS 5 qual.	IS 6 sync.	IS 7 [illegible]	IS 8 inno.
1 Selection of low-impact materials										
1.1 Clean materials	●		✔	✔	✔	✔	✔	✔	✔	✔
1.2 Renewable materials		❍		✔		✔				
1.3 Low energy content materials										
1.4 Recycled materials	●	❍	✔	✔	✔	✔				
2 Reduction of materials usage										
2.1 Reduction in weight	●	●	✔	✔	✔	✔	✔	✔	✔	✔
2.2 Reduction in volume				✔						
3 Optimization of production techniques										
3.1 Clean production techniques		❍	✔	✔					✔	
3.2 Fewer production steps		●	✔	✔				✔		
3.3 Low/clean production energy		❍	✔	✔						
3.4 Less production waste	●	●	✔	✔					✔	
3.5 Few/clean production consumables			✔	✔						
4 Optimization of distribution system										
4.1 Less/clean/reusable packaging	●	❍	✔	✔		✔		✔	✔	
4.2 Energy-efficient transport mode										
4.3 Energy-efficient logistics		❍	✔	✔						
5 Reduction of impact during use										
5.1 Low energy consumption	●	❍	✔	✔	✔	✔	✔	✔		✔
5.2 Clean energy source		●	✔							
5.3 Few consumables needed		❍	✔							
5.4 Clean consumables			✔	✔	✔					
5.5 No waste of energy/consumables		❍	✔			✔				
6 Optimization of initial lifetime										
6.1 High reliability and durability	●	●	✔	✔	✔	✔	✔	✔		✔
6.2 Easy maintenance and repair		❍	✔	✔		✔			✔	
6.3 Modular /adaptable product structure		●	✔	✔		✔		✔	✔	✔
6.4 Classic design										
6.5 Strong product-user relation										
7 Optimization of end-of-life system										
7.1 Reuse of product		❍	✔	✔	✔			✔		
7.2 Remanufacturing/ refurbishing	●	❍	✔	✔	✔	✔			✔	
7.3 Recycling of materials	●		✔	✔	✔	✔	✔	✔	✔	✔
7.4 Safe incineration (energy recovery)										
7.5 Safe disposal of product remains										
@ New concept development										
@.1 Dematerialization										
@.2 Shared product use			✔	✔						
@.3 Integration of functions		●	✔	✔	✔	✔	✔	✔		✔
@.4 Functional optimization										

●: The DFE principle was motivated by a large number of internal stimuli
❍: The DFE principle was motivated by a significant number of internal stimuli
✔: The specific internal stimulus was mentioned at least twice for the DFE principle in question

Figure 6.10 *Overview of the findings concerning the internal stimuli per DFE principle (in absolute and relative terms), and the specific fields of influence of the eight types of internal stimuli*

.2.5 Barriers per DFE principle

Shifting the focus from stimuli to barriers for DFE, Figure 6.8 presents an overview of the barriers that were mentioned for each of the DFE principles. The companies studied mentioned a total of 414 barriers for 322 of the 596 suggested DFE improvement options. One or more barriers were mentioned for all DFE principles represented by more than one DFE improvement option.

Looking at the ***absolute figures*** presented in the bar chart in Figure 6.8 we see that a large number of barriers were mentioned for DFE principles:

- 1.1 'Selection of clean materials',
- 2.1 'Reduction in weight',

- 4.1 'Less/clean/reusable packaging',
- 5.1 'Low energy consumption',
- 6.1 'High reliability and durability' and
- 7.3 'Recycling of materials'.

As applied in the case of the stimuli discussed in the above, these absolute figure mean very little since they strongly relate to the number of DFE improvement options categorized in the specific DFE principle.

The ***relative figures***, i.e. the number of barriers in comparison with the number of options for a certain DFE principle, give us a greater understanding of the influence of the barriers in relation to the DFE principles. A large number of barriers in relative terms were perceived for some DFE principles, meaning that more than one barrier was mentioned for more than half the suggested DFE options. This is the case for the following DFE principles:

- 1.1 'Selection of clean materials' (80 barriers for 54 of 80 options),
- 1.2 'Renewable materials' (5 barriers for 4 of 5 options) and
- 6.1 'High reliability and durability' (30 barriers for 25 of 38 options).

To a lesser extent this also applies for DFE principles 2.1 'Reduction in weight', 2.2 'Reduction in volume', 3.1 'Clean production techniques', 4.1 'Less/clean/reusable packaging', 5.1 'Low energy consumption', 5.3 'Few consumables needed', 5.4 'Clean consumables', 6.4 'Classic design', 7.1 'Reuse of product' and @.4 'Functional optimization'. Figure 6.8 shows quite clearly that the types of barriers mentioned for these DFE principles are varied.

Relatively few barriers were mentioned for DFE principles:

- 3.3 'Low/clean production energy' (2 barriers for 2 of 10 options),
- 7.3 'Recycling of materials' (43 barriers for 33 of 77 options) and
- @.3 'Integration of functions' (6 barriers for 4 of 11 options).

The fact that DFE principle @.3 'Integration of functions' was associated with very few barriers is somewhat of a surprise since DFE strategy @ 'New concept development' is thought to be difficult to realize. In a later stage we will analyze whether the companies did indeed implement these DFE options.

Do certain types of barrier relate to specific DFE principles? If we look at which barriers are the most dominant in relation to the individual DFE principles, we see that most DFE principles are associated with a mix of different barriers, and not with only one or two barriers in particular. For example: the barrier 'No clear environmental benefit' was not mentioned for any DFE principle in particular; in absolute terms it was mentioned the most often for DFE principles:

- 1.1 'Selection of clean materials',
- 2.1 'Reduction in weight',
- 3.4 'Less production waste',
- 4.1 'Less/clean/reusable packaging',
- 6.1 'High reliability and durability' and
- 7.1 'Reuse of product'.

These findings indicate that the companies studied have no doubts as to the environmental benefits of certain DFE strategies in particular.

This also applies with regard to the barrier 'Not our responsibility'; in absolute terms it was mentioned the most frequently for DFE principles 1.1 'Selection of clean materials', 2.1 'Reduction in weight', 5.1 'Low energy consumption', 6.1 'High reliability and durability', 7.2 'Remanufacturing/refurbishing' and 7.3 'Recycling of materials'.

The barrier 'No alternative solution available' is less evenly distributed, being mentioned mainly for DFE principles 1.1 'Selection of clean materials' and 3.5 'Few/clean production consumables'.

The barrier 'Not yet required by legislation' was mentioned a few times only, concentrating on DFE principle 1.1 'Selection of clean materials'. The barrier 'Not yet required by customers' is mentioned slightly more frequently, but not for any particular DFE principle.

The barrier 'Commercial disadvantage' is not focused on a specific DFE principle either; it is mentioned for DFE principles 1.1 'Selection of clean materials', 2.1 'Reduction in weight', 3.4 'Less production waste', 4.2 'Energy-efficient transport mode', 6.4 'Classic design' and 7.3 'Recycling of materials'.

However, the barrier 'Conflict with functional requirements' is strongly related to the DFE principles 1.1 'Selection of clean materials' and 2.1 'Reduction in weight'; and to a lesser extent to 5.1 'Low energy consumption', 6.1 'High reliability and durability' and 7.3 'Recycling of materials'.

No barrier of the type 'No innovation opportunities' was mentioned. The barrier 'Investment in specific product is fruitless' was not related to any specific DFE principle. This is not surprising since it does not concern any DFE option in particular.

The barrier 'Insufficient capacity in time' was the most often mentioned one for DFE principles @.1 'Dematerialization', @.3 'Integration of functions' and @.4 'Functional optimization', belonging to the DFE strategy 'New Concept Development'. This can be explained by the fact that this strategy required time-consuming product innovation as opposed to modification.

The barrier 'Insufficient knowledge' was mentioned twice only, relating to DFE principle 1.1 'Selection of clean materials'. This is hardly surprising either since the companies could ask their IC consultant or an external consultancy for support.

Figure 6.11 summarizes the findings on the internal stimuli mentioned above. It indicates those DFE principles for which many barriers were mentioned (in absolute and relative terms). It also shows to what extent the types of barrier were mentioned for the various DFE principles (this is indicated only if a specific barrier was mentioned at least twice for one DFE principle).

In conclusion, the empirical findings on barriers for the different DFE principles are as follows:

- *In absolute terms, many barriers were mentioned for 6 DFE principles, each of which belong to a different DFE strategy. In relative terms, many barriers were perceived for 13 DFE principles, covering all eight DFE principles. Only 5 DFE principles were said to have many barriers in absolute and relative terms: 'Selection of clean materials', 'Reduction in weight', 'Less/clean/reusable packaging', 'Low energy consumption' and 'High reliability/durability'.*
- *Most DFE principles are associated with a combination of barriers, and not one or two in particular. An exception here is DFE strategy @ 'New concept development', for which the barrier 'Insufficient time' was mentioned the most frequently.*
- *Most barrier types do not relate to a certain DFE strategy in particular. Exceptions are 'Insufficient time', which mainly counts for DFE strategy @ 'New concept development' and 'Not yet required by legislation', mainly associated with 'Selection of clean materials' and 'Less/clean/reusable packaging'.*
- *The companies failed to even mention the barrier 'No innovation opportunities'. We may not assume that all DFE options suggested were perceived as interesting opportunities for product innovation. The companies probably saw this barrier as irrelevant because the other types of barrier were predominant.*

DFE strategies and principles	Many B (abs)	Many B (rel)	B1 envi.	B2 resp.	B3	B4	B5	B6	B7	B8	B9	B10	B11
1 Selection of low-impact materials													
1.1 Clean materials	✘	✘	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔
1.2 Renewable materials		✘	✔										
1.3 Low energy content materials													
1.4 Recycled materials									✔				
2 Reduction of materials usage													
2.1 Reduction in weight	✘	✘	✔	✔	✔		✔	✔	✔		✔	✔	
2.2 Reduction in volume		✘							✔				
3 Optimization of production techniques													
3.1 Clean production techniques		✘	✔	✔	✔			✔	✔		✔		
3.2 Fewer production steps									✔			✔	
3.3 Low/clean production energy													
3.4 Less production waste			✔					✔					
3.5 Few/clean production consumables					✔				✔				
4 Optimization of distribution system													
4.1 Less/clean/reusable packaging	✘	✘	✔	✔		✔	✔		✔			✔	
4.2 Energy-efficient transport mode								✔					
4.3 Energy-efficient logistics													
5 Reduction of impact during use													
5.1 Low energy consumption	✘	✘		✔	✔		✔	✔	✔		✔	✔	
5.2 Clean energy source									✔				
5.3 Few consumables needed		✘					✔						
5.4 Clean consumables		✘											
5.5 No waste of energy/consumables													
6 Optimization of initial lifetime													
6.1 High reliability and durability	✘	✘	✔	✔	✔		✔		✔			✔	
6.2 Easy maintenance and repair								✔	✔				
6.3 Modular /adaptable product structure									✔				
6.4 Classic design		✘						✔					
6.5 Strong product-user relation													
7 Optimization of end-of-life system													
7.1 Reuse of product		✘	✔	✔				✔					
7.2 Remanufacturing/ refurbishing				✔				✔	✔				
7.3 Recycling of materials	✘		✔	✔	✔		✔	✔	✔			✔	
7.4 Safe incineration (energy recovery)													
7.5 Safe disposal of product remains													
@ New concept development													
@.1 Dematerialization													
@.2 Shared product use													
@.3 Integration of functions												✔	
@.4 Functional optimization		✘										✔	

✘ : DFE principles motivated because of the many barriers

✔: Barrier specifically mentioned at least twice for the DFE principle involved

Figure 6.11 *Overview of the findings on number of barriers mentioned per DFE principle (in absolute and relative terms) and the specific fields of influence of the eleven types of barrier*

6.2.6 Conclusions

In the preceding sections we have dealt with the external and internal stimuli and barriers per DFE principle as separate subjects. In the following we shall simultaneously assess the stimuli and barriers per DFE principle in order to build up a picture of the pros and cons per DFE principle as perceived by the companies studied in this research. A comparison of Figure 6.6, Figure 6.7 and Figure 6.8, presenting the external stimuli, the internal stimuli and the barriers for the suggested DFE improvement options, resulted in Figure 6.12: an overview of stimuli and barriers per DFE principle.

[illegible]	[illegible]	[illegible]	[illegible]
1 Selection of low-impact materials			
1.1 'Clean' materials	Government regulation Customer demands Supplier developments	Environmental benefit Cost reduction Image improvement New market opportunities Other commercial benefit	Conflict with funct. requirement. No alternative available
1.2 Renewable materials	--	Cost reduction New market opportunities	No clear environmental benefit
1.3 Low energy content materials	--	--	--
1.4 Recycled materials	Government regulation Customer demands	Environmental benefit Cost reduction Image improvement New market opportunities	Conflict with funct. requirement. Commercial disadvantage
2 Reduction of materials usage			
2.1 Reduction in weight	Customer demands Government regulation	Cost reduction Environmental benefit	Conflict with funct. requirement.
2.2 Reduction in volume	--	Cost reduction	Conflict with funct. requirement.
3 Optimization of production techniques			
3.1 'Clean' production techniques	Government regulation	Environmental benefit Cost reduction	Conflict with funct. requirement.
3.2 Fewer production steps	--	Environmental benefit Cost reduction	Conflict with funct. requirement. Insufficient capacity in time
3.3 Low/'clean' production energy	--	Cost reduction Environmental benefit	Not our responsibility Conflict with funct. requirement.
3.4 Less production waste	Governmental regulation	Environmental benefit Cost reduction	No clear environmental benefit Commercial disadvantage Other: Fixed logistic planning
3.5 Few/'clean' production consumables	Governmental regulation	Environmental benefit Cost reduction	No alternative available Conflict with funct. requirement.
4 Optimization of distribution system			
4.1 Less/'clean'/reusable packaging	Supplier developments Customer demands Government regulation	Environmental benefit Cost reduction	No clear environmental benefit Conflict with funct. requirement.
4.2 Energy-efficient transport mode	--	--	Commercial disadvantage
4.3 Energy-efficient logistics	Government regulation	Cost reduction Environmental benefit	Other: Series still too small Seasonal influences Complex supply logistics
5 Reduction of impact during use			
5.1 Low energy consumption	Government regulation Customer demands	Environmental benefit Cost reduction Image improvement New market opportunities	Conflict with funct. requirement.
5.2 'Clean' energy source	Government regulation Other: Proposal engineering consultancy	Environmental benefit	Conflict with funct. requirement.
5.3 Few consumables needed	Customer demands Government regulation	Environmental benefit	Not yet required by customers
5.4 'Clean' consumables	Customer demands Supplier developments	Image improvement Cost reduction	Not our responsibility No alternative available Not yet required by legislation Conflict with funct. requirement. Insufficient capacity in time Other: Redesign necessary
5.5 No waste of energy/consumables	Customer demands Government regulation	New market opportunities	Not our responsibility No alternative available Not yet required by customers Conflict with funct. requirement.
6 Optimization of initial lifetime			
6.1 High reliability and durability	Customer demands	Increase of product quality Environmental benefit	No clear environmental benefit Conflict with funct. requirement.
6.2 Easy maintenance and repair	Government regulation Customer demands	Cost reduction Environmental benefit New market opportunities Other commercial benefit	Commercial disadvantage Conflict with funct. requirement.
6.3 Modular/adaptable structure	Customer demands	New market opportunities Environmental benefit Cost reduction Other commercial benefit	Conflict with funct. requirement.

6.4 Classic design	Govt. regulation anticipated	--	Commercial disadvantage
6.5 Strong product-user relation	--	--	--
7 Optimization of end-of-life system			
7.1 Reuse of product	Customer demands	Environmental benefit Cost reduction Image improvement	No clear environmental benefit Not our responsibility Commercial disadvantage Other: Lifetime is 15 years No market interest
7.2 Remanufacturing/ refurbishing	Government regulation	Environmental benefit Cost reduction New market opportunities Other commercial benefit	Not our responsibility Conflict with funct. requirement.
7.3 Recycling of materials	Government regulation Customer demands	Environmental benefit Cost reduction Image improvement Other commercial benefit	Conflict with funct. requirement. Commercial disadvantage Not our responsibility
7.4 Safe incineration (energy recovery)	--	--	No clear environmental benefit Other: Other priorities
7.5 Safe disposal of product remains	--	--	No clear environmental benefit No alternative available Commercial disadvantage
@ New concept development			
@.1 Dematerialization	--	Other: New business concept	Insufficient capacity in time
@.2 Shared product use	--	New market opportunities Environmental benefit	Commercial disadvantage Conflict with funct. requirement. No new investment wanted
@.3 Integration of functions	--	Cost reduction Image improvement New market opportunities Interesting innovation opportunity	Insufficient capacity in time Conflict with funct. requirement.
@.4 Functional optimization	--	Environmental benefit Image improvement Other commercial benefit	Conflict with funct. requirement.

Figure 6.12 *Stimuli and barriers mentioned most frequently by the companies studied, categorized per DFE principle*

Figure 6.12 clearly shows how the stimuli and barriers are distributed among the 33 DFE principles. For example, DFE principle 4.2 'Energy-efficient transport mode' is lacking in stimuli but is associated with the barrier 'commercial disadvantage'. Conversely, DFE principle 6.3 'Modular/adaptable product structure' has various external and internal stimuli and only one frequently mentioned barrier. We may expect that the options of DFE principle type 6.3 are far more likely to be realized than options of DFE principle type 4.2. In addition to the conclusions drawn in the foregoing at the level of individual DFE principles, we can now use Figure 6.12 to help us draw some conclusions at the aggregated level of DFE strategies.

External stimuli per DFE strategy

First, the DFE strategies differ in terms of the amount and diversity of external stimuli mentioned by the companies. No external stimuli were perceived for DFE strategy @ 'New concept development'. A limited number of external stimuli was perceived for DFE strategy 3 'Optimization of production techniques', all of which were related to actual or pending governmental regulation. A considerable number of external stimuli were mentioned for DFE strategy 7 'Optimization of end-of-life system', usually of the types 'government regulation' or 'customer demands'. This applies to both DFE strategy 2 'Reduction of materials usage' (strongly focusing on DFE principle 2.1 'Reduction in weight'), and DFE strategy 6 'Optimization of initial lifetime'. However, for the latter ***competitor's initiatives*** were mentioned twice as an external stimulus. This stimulus was mentioned only 4 times in all (also for DFE principles 5.1 'Low energy consumption' and 6.1 'High reliability and durability').
Supplier developments play a considerable role with regard to DFE strategy 1 'Selection of low-impact materials' only (mainly DFE principle 1.1 'Selection of clean materials') and DFE strategy 4 'Optimization of distribution system' (mainly DFE principle 4.1 'Less/clean/reusable packaging'). Figure 6.6 already taught us that the ***industrial sector*** was represented as an external driver only for DFE strategies 1 'Selection of low-impact materials' (twice), 5 'Reduction of impact during use' (once) and 7 'Optimization of end-of-life system' (twice). We may conclude that the most heterogeneous

combinations of external stimuli are mentioned for DFE strategies 1 'Selection of low-impact materials', 5 'Reduction of impact during use', 6 'Optimization of initial lifetime' and 7 'Optimization of end-of-life system'.

Internal stimuli per DFE strategy

A similar analysis of the internal stimuli shows that these factors are more homogeneously spread over the DFE strategies than the external ones. Figure 6.12 shows that the most common internal stimuli are the perceived ***environmental benefit*** and expected ***cost reduction***. Cost reduction is remarkably influential with regard to DFE strategy 2 'Reduction of materials usage'.
However, there are certain differences too. For instance: the internal stimulus ***image improvement*** has the most influence with regard to DFE strategies 1 'Selection of low-impact materials', 5 'Reduction of impact during use', 7 'Optimization of end-of-life system' and @ 'New concept development'. Furthermore, the influence of the internal stimulus ***increase of product quality*** is the most prominent with regard to DFE strategies 2 'Reduction of materials usage' and 6 'Optimization of initial lifetime'. The stimulus ***interesting innovation opportunities*** has the most influence on DFE strategy @ 'New concept development'.
Finally, certain DFE strategies are more often associated with the internal stimulus ***new market opportunities*** than others. We may assume that the companies see these strategies as the most innovative ones. The DFE strategies perceived as the most innovative ones are DFE strategies 1 'Selection of low-impact materials', 5 'Reduction of impact during use', 6 'Optimization of initial lifetime' and @ 'New concept development'. The factor of 'new market opportunities' was mentioned frequently as an internal stimulus for at least two DFE principles belonging to each of these four strategies. Moreover, a unique internal stimulus described as 'may result in new business concept' was mentioned for DFE strategy @ 'New concept development'.

Barriers per DFE strategy

If we step back and look at the barriers presented in Figure 6.12 as a whole, we see that a barrier common to many DFE strategies is ***conflict with functional product requirements***. It goes without saying that differences are to be found as well. A remarkable barrier is ***no clear environmental benefit*** since we might expect the environmental benefit of each suggested DFE improvement option to be a convincing factor. Although this barrier was mentioned for DFE strategies 1 'Selection of low-impact materials', 3 'Optimization of production techniques' and 4 'Optimization of distribution system', it seems to have the most influence on DFE strategy 7 'Optimization of end-of-life system'.
Another barrier is defined as ***not our responsibility***. This was mentioned for most DFE strategies, yet it seems to have the greatest influence in relation to DFE strategies 5 'Reduction of impact during use' and 7 'Optimization of end-of-life system'. The barriers ***not yet required by customers*** and ***not yet required by legislation*** are mainly of influence in relation to DFE strategy 5 'Reduction of impact during use'. These barriers reflect an attitude similar to 'not our responsibility': we do not feel it is our task to realize the suggested DFE option, sometimes referred to as 'it does not fit into our strategy'. Furthermore, the barrier ***no alternative solution available*** has the most influence on DFE strategies 1 'Selection of low-impact materials', 3 'Optimization of production techniques', 5 'Reduction of impact during use' and 7 'Optimization of end-of-life system'. It came as no surprise to us to see that ***insufficient time*** was mentioned mainly in connection with DFE strategy @ 'New Business Concept' and, to a lesser extent, DFE strategy 3 (DFE principle 3.2 'Fewer production steps in particular').

6.3 The influence of stimuli and barriers

6.3.1 Influence of stimuli and barriers on the success rate of DFE options in general

The foregoing presented the stimuli and barriers in terms of number and type. Some conclusions were drawn on the notion that the more times a specific factor was mentioned, the greater its influence on the company's decision to realize or reject a certain DFE improvement option. In order to learn which stimuli and barriers are the most influential ones in practice, the next section addresses the relation between the stimuli and barriers for a certain DFE improvement option on the one hand, and the success rate or degree of realization on the other.

Chapter 3 introduced the method for measuring the DFE performance of the companies that participated in the 1995 IC EcoDesign project. This method implies the assessment of all suggested DFE improvement options (a total of 596) as to the extent of realization ('success rate'), the resulting product or process change, the extent to which an option was new for the company ('newness') and the specific stimuli and barriers that motivated the company to either reject or realize it. The nine success rates distinguished are listed in Figure 3.5 in Chapter 3.

The success rates are clustered into four groups. The first group contains only grade 0 options, implying that they were ***rejected*** without any study. The second group includes grades 1, 2 and 3, indicating that the company had shown a certain amount of ***interest*** in the option but without much success so far. The third group clusters grades 4, 5 and 6; options attributed with these grades are ***prioritized***. Only options with success rate 6 are actually ***realized***. Finally, the fourth group contains success rates 7 or 8, categorized under the heading ***not considered***: these options fall beyond the range 0 to 6 in the sense that they should be classified as neither rejected nor of interest nor prioritized.

6.3.2 Influence of external stimuli

The influence of the external stimuli on the success rate of DFE improvement options is discussed first of all. Figure 6.13 shows the external stimuli (totaling 130) perceived by the companies, categorized according to the success rates of the relevant option, and stacked in accordance with the type of external stimuli distinguished.

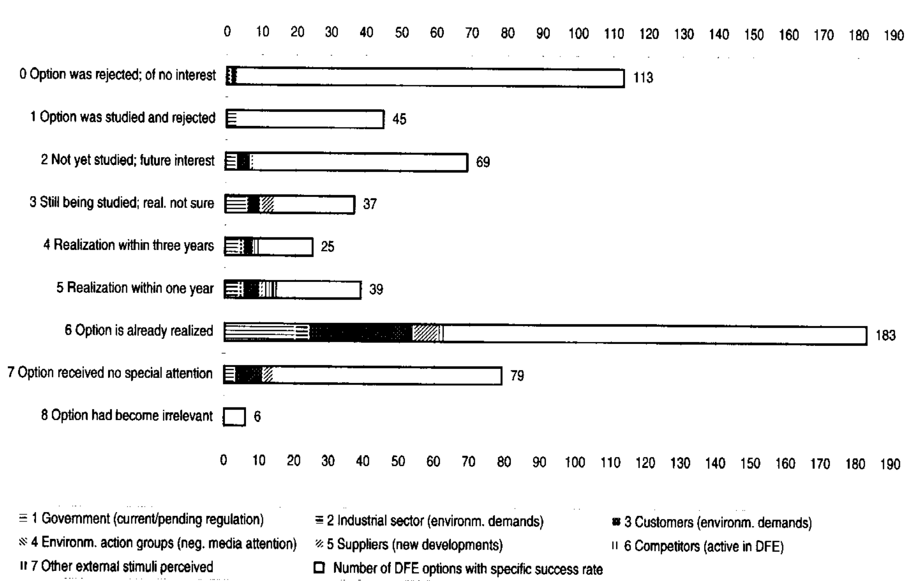


Figure 6.13 *The external stimuli (130 in all) categorized according to the success rates of the DFE improvement options, and stacked according to type of stimulus*

Figure 6.13 shows yet again that the external stimuli mentioned most frequently are 'government regulation' and 'environmental customer demands'. This applies with regard to almost all categories of success rate 2 to 6. As we expected, the number of external stimuli mentioned for DFE options with success rates 3, 4, 5 and 6 is higher than the number of external stimuli for options with success rates 0 and 1. The relatively high number of external stimuli for DFE options with a success rate of 7 is not surprising either since they relate to general design options which the companies see as prerequisite

for a well designed product. No stimuli were recorded for those options that had become irrelevant (success rate 8).
Finally, Figure 6.14 shows the percentage of DFE options with a specific success rate related to one or more external stimuli. The table in Figure 6.14 was derived from Figure 6.13.

Success rate	# DFE options	# DFE options with no external stimulus	# DFE options with external stimulus	% DFE options with external stimulus
0	113	110	3	3 %
1	45	42	3	7 %
2	69	62	7	10 %
3	37	26	11	30 %
4	25	17	8	32 %
5	39	27	12	31 %
6	183	128	55	30 %
7	79	67	12	15 %
8	6	6	0	0 %
Total:	596	485	111	19%

Figure 6.14 The percentages of DFE options with at least one external stimulus per success rate category

As expected, in the categories of success rates 3, 4, 5 and 6 the number of DFE options associated with at least one external stimuli is relatively high: 30%, 32%, 31% and 30% respectively. These are considerably lower for the DFE options with success rates 0 (3%), 1 (7%) and 2 (10%).
Of all 111 DFE options ***with an external stimulus***, 75 (68%) were prioritized (success rates 4, 5 or 6). As expected, there were few options that were motivated by an external stimulus but were still rejected; only six DFE options were rejected (success rates 0 or 1) while an external stimulus had still been mentioned.

It was more surprising to see that as many as 172 of the 485 DFE options ***with no external stimulus*** (35%) were still prioritized. Limiting our scope to the options that were realized (success rate 6 only), we see that 128 of the 485 DFE options for which no external stimuli were mentioned were still realized (26%). These two percentages are unexpectedly high since environmental management literature states that external drivers are usually prerequisite for environmental initiatives in industry. Conversely, we found that only 30% of ***all DFE options realized*** had been motivated by an external stimulus. This implies that as many as 70% of all DFE options with success rate 6 were realized, regardless of the absence of external stimuli. We expected that these DFE options, which although they were realized were not motivated by an external stimulus, were motivated by strong internal stimuli instead. Further analysis showed that this was indeed the case. Two-thirds of these DFE options were motivated by two or more internal stimuli; one-third by only one internal stimulus (a barrier was mentioned for only 20% of these options). The types of internal stimuli varied; 'environmental benefit', 'cost reduction' and 'image improvement' were mentioned the most frequently.

The influence of individual external stimuli

So far we have estimated the importance of a specific external stimulus according to the frequency by which it was mentioned. However, we can obtain a better picture of the influence exerted by a stimulus if we look at the extent to which a company has managed to realize a DFE option for which a specific stimulus had been mentioned. This analysis was performed by selecting the DFE options of a certain type of stimulus and subsequently assessing their success rates.
Figure 6.15 shows the results of this analysis.

External stimuli	# DFE options	Success rate 4	Success rate 5	Success rate 6	Total ('prioritized')
1 Government	43	9 %	9 %	47 %	65 %
2 Industrial sector	7	14 %	14 %	57 %	86 %
3 Customers	56	5 %	9 %	54 %	68 %
4 Env. action groups	--	--	--	--	--
5 Suppliers	16	--	6 %	44 %	50 %
6 Competitors	4	25 %	50 %	25 %	100 %

Figure 6.15 *The extent to which DFE options for which a specific external stimulus had been mentioned were prioritized (attributed with a success rate of 4, 5 or 6)*

This figure leads us to draw to some quite distinct conclusions. The external stimuli 'competitors' and 'industrial sector' have a strong influence yet are mentioned for a few DFE options only. 'Influential' implies that high percentages of DFE options for which this stimulus was mentioned were realized (success rate 6) and prioritized (success rate 4, 5 or 6). All four DFE options prioritized thanks to 'competitor activities' were prioritized; only 25% had been realized already. The external stimuli which have slightly less influence but were mentioned far more frequently are 'customers' and 'government'. Therefore, the three most influential external stimuli are: 1) Customer demands, 2) Government regulation and 3) Industrial sector initiatives.

6.3.3 The influence of internal stimuli

An assessment was also made of the influence of internal stimuli on the success rates of the related DFE improvement options. Figure 6.16 shows the number and types of internal stimuli mentioned for all DFE options, categorized according to their success rates.

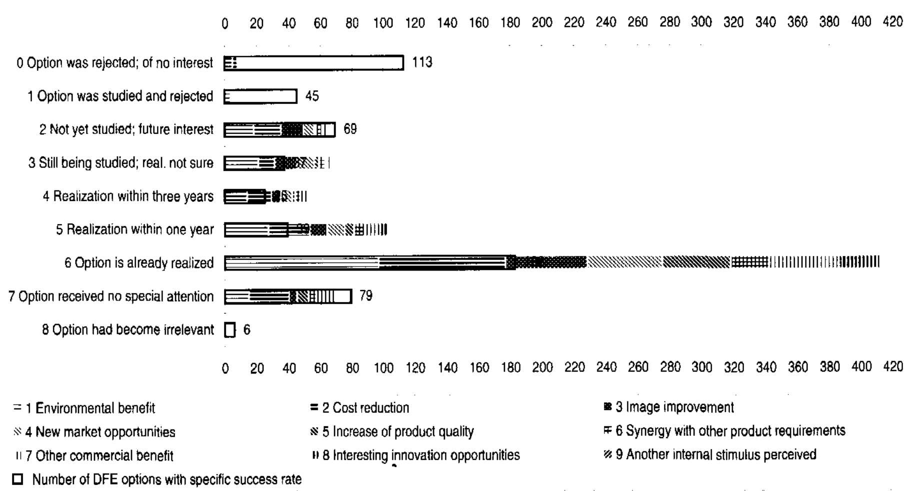


Figure 6.16 *The internal stimuli (130 in all) categorized according to the success rates of the DFE improvement options, stacked according to the type of stimulus*

Figure 6.16 clearly shows that internal stimuli were perceived for many of the DFE options with a success rate of 3, 4, 5 and 6; moreover, the average number of internal stimuli mentioned per DFE option exceeds 2. As expected, this is in contrast to the DFE options with success rates 0 or 1, for which hardly any internal stimuli were mentioned. The figure also shows that the most frequently mentioned types of internal stimuli are 'environmental benefit' and 'cost reduction' expected for a certain DFE improvement option. The types of stimuli mentioned are more or less the same in the higher success rate categories; a combination of different internal stimuli is common for options with success rates 2 to 6. An overview of the number of DFE options with or without internal stimuli per category of success rate (derived from Figure 6.16) is presented in Figure 6.17.

Success rate	# DFE options	# DFE options with no internal stimulus	# DFE options with internal stimulus	% DFE options with internal stimulus
0	113	106	7	6 %
1	45	37	8	18 %
2	69	31	38	55 %
3	37	7	30	81 %
4	25	1	24	96 %
5	39	1	38	97 %
6	183	35	148	81 %
7	79	33	46	58%
8	6	6	0	0 %
Total:	596	257	339	57%

Figure 6.17 The percentages of DFE options with at least one internal stimulus per success rate category

In line with our expectations, the table in Figure 6.17 shows that in the categories of success rates 3, 4, 5 and 6 there were many DFE options associated with at least one internal stimulus: 81%, 96%, 97% and 81% respectively. This implies that only 19% of the DFE options with success rate 6 were realized regardless of the absence of internal stimuli. A limited number of DFE options (15 in all) were rejected (success rates 0 or 1) regardless of whether internal stimuli had been mentioned or not; the stimulus was usually 'expected environmental benefit', indicating that this stimulus on its own was not always sufficiently convincing. Nevertheless, this stimulus does suffice occasionally: a total of 14 DFE options were prioritized which were only motivated by the stimulus 'environmental benefit' (DFE principle types 1.1 'Selection of clean materials', 1.4 'Recycled materials', 3.5 'Few/clean production consumables', 5.3 'Few consumables needed', 7.1 'Reuse of product', 7.3 'Recycling of materials' (5 options) and 7.4 'Safe incineration'). The high percentage of DFE options with an internal stimulus in the case of success rate 7 is hardly surprising considering that the companies studied already regarded these aspects as prerequisite for well designed products.

Also anticipated was the large number of prioritized DFE options that were associated with at least one internal stimulus: 210 of the 339 DFE options for which internal stimuli were mentioned were attributed with a success rate of 4, 5 or 6 (62%). With regard to the success rates of DFE options that were ***not motivated*** by an internal stimulus we see that 37 of the 257 DFE options with no internal stimulus were still prioritized (14.4%). The number of DFE options which, although not motivated by internal stimulus, were still realized (success rate 6) is 35 or 13.6%.

The influence of internal stimuli

So far we have estimated the importance of internal stimuli on the basis of how many times they were mentioned. However, we can obtain an even better picture of the influence exerted by a specific stimulus if we consider the extent to which a company had managed to realize a DFE option for which that stimulus had been mentioned. To this end we selected the DFE options of a certain stimulus type and assessed their success rates. The results of this analysis are shown in Figure 6.18.

Internal stimuli	# DFE options	Success rate 4	Success rate 5	Success rate 6	Total ('prioritized')
1 Environmental benefit	201	7 %	13 %	48 %	69 %
2 Cost reduction	177	9 %	15 %	45 %	68 %
3 Image improvement	103	6 %	11 %	50 %	66 %
4 New market opportunities	84	8 %	13 %	56 %	77 %
5 Increase of product quality	63	3 %	10 %	68 %	81 %
6 Synergy other pr. requirements	48	6 %	15 %	50 %	71 %
7 Other commercial benefit	82	7 %	12 %	54 %	73 %
8 Innovational opportunities	36	6 %	14 %	72 %	92 %

Figure 6.18 *The extent to which DFE options (for which a specific internal stimulus was mentioned) were prioritized (attributed with a success rate 4, 5 or 6)*

We have already seen that the first three internal stimuli 'environmental benefit', 'cost reduction' and 'image improvement' were the most frequently mentioned. However, Figure 6.18 shows quite clearly that they are not the ones that exert the most influence. If we focus on the percentages of DFE options prioritized we see that three other stimuli have the most influence. Many DFE options associated with the stimuli 'innovational opportunities', 'increase of product quality' or 'new market opportunities' were prioritized or even realized. The top three of most influential internal stimuli therefore consists of: 1) Innovational opportunities, 2) Increase of product quality and 3) New market opportunities.

6.3.4 The influence of barriers

Finally, we made an assessment of the influence of barriers (mentioned by the companies studied) on the DFE improvement options success rates. The results are shown in Figure 6.19, presenting the barriers, categorized according to the success rate of the DFE options and stacked according to the type of barrier.

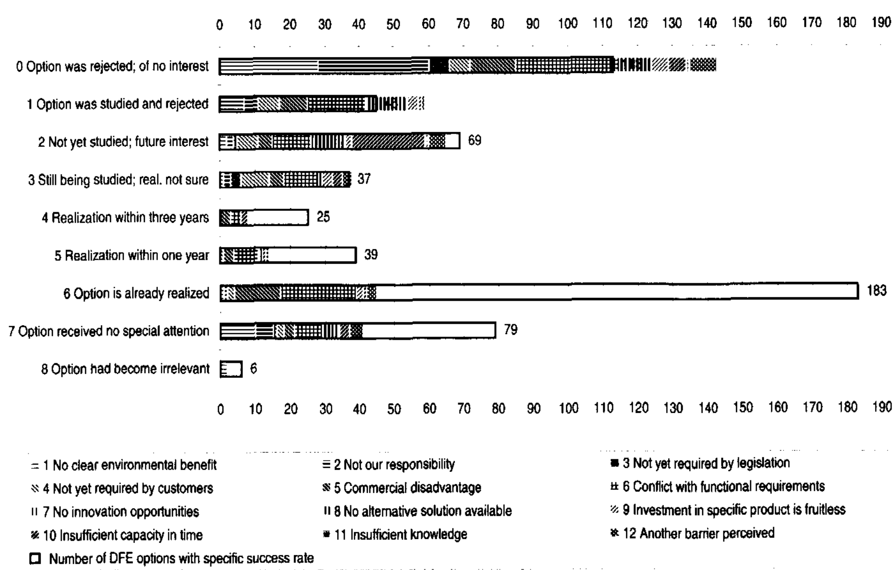


Figure 6.19 *The barriers (414 in all) categorized according to the success rates of the DFE improvement options, and stacked according to the type of barrier*

With regard to the categories of success rates 4, 5 and 6, a barrier was mentioned for about 25% of the DFE options; in these cases the number of barriers was limited to one barrier per DFE option. As we expected, many more barriers were mentioned in those DFE option categories with a success rate of 0 and 1: at least one barrier was mentioned for almost all these DFE options. Two barriers were perceived for one DFE option in about half of these. DFE options with success rates 2 and 3 are situated clearly between these two extremes. Can we therefore assume that all DFE options without barriers were prioritized? No; the empirical data reveals that 39 DFE options with no barriers were still attributed with a success rate of 0, 1, 2 or 3.

The rejected DFE options (success rates 0 or 1) show a wide range of different types of barriers. Conversely, the barriers mentioned for the prioritized DFE options (success rates 4, 5 or 6) relate mainly to two types of barrier: 'Conflict with functional product requirements' and 'Commercial disadvantage'. Since these barriers were not responsible for blocking the priority of the related DFE options, they were characterized as ***'initial barriers'***. In contrast, the barriers 'no environmental benefit' and 'not our responsibility' are related mainly to the rejected DFE options (success rates 0 or 1). They were not mentioned with regard to prioritized DFE options (success rate 4, 5 or 6). Therefore these two types of barriers would seem to be ***'no-go barriers'***. Not surprisingly, the barrier 'insufficient capacity in time' was mentioned relatively frequently for DFE options with success rate 2 ('option is of future interest'). The barrier 'no alternative available' was mentioned only for those DFE options with success rates 0, 1 or 2. This would seem to be a third 'no-go barrier', leading to the rejection or postponement of the suggested DFE option.
In addition to Figure 6.19 above, Figure 6.20 presents the numbers of DFE options with or without at least one perceived barrier.

Success rate	# DFE options	# DFE options with no barrier	# DFE options with a barrier	% DFE options with a barrier
0	113	6	107	95 %
1	45	2	43	96 %
2	69	22	47	68 %
3	37	9	28	76 %
4	25	18	7	28 %
5	39	26	13	33 %
6	183	141	42	23 %
7	79	46	33	42 %
8	6	4	2	33 %
Total:	596	274	322	54%

Figure 6.20 Percentages of DFE options with at least one barrier per success rate category

The table makes it clear that barriers were mentioned for many DFE options. As expected, the number of DFE options for which a barrier was perceived is the lowest for the DFE options that were prioritized (with success rates 4, 5 or 6): 28%, 33% and 23% respectively. As also expected, the number of DFE options for which barriers were mentioned is very high for DFE options with a success rate of 0 (95%) or 1 (96%). The DFE options with a success rate of 2 or 3 show percentages somewhere between these two extremes. As foreseen, many DFE options for which no barrier had been perceived were prioritized: 185 of the 274 DFE options with no barriers were attributed with a success rate of 4, 5 or 6 (68%). Despite the barriers mentioned, 62 of the 322 DFE options for which a barrier was mentioned were prioritized (19%); a total of 42 DFE options with a barrier were even realized (13%).

The influence of barriers

In order to obtain a clearer picture of the influence exerted by the various types of barrier we assessed the extent to which a company had managed to realize a DFE option associated with a certain barrier. The success rates of the DFE options involved were assessed per barrier type. The results of this analysis are shown in Figure 6.21.

Barrier type	# DFE options	Success rate 4	Success rate 5	Success rate 6	Total ('prioritized')
1 No clear environmental benefit	51	--	--	2 %	2 %
2 Not perceived as responsibility	46	--	--	2 %	2 %
3 Not yet required by legislation	11	--	--	--	--
4 Not yet required by customers	31	--	3 %	7 %	10 %
5 Commercial disadvantage	51	6 %	6 %	26 %	37 %
6 Conflict functional pr. requirem.	108	3 %	7 %	20 %	30 %
7 No innovation opportunities	--	--	--	--	--
8 No alternat. solution available	37	--	3 %	--	3 %
9 Investment is fruitless	15	--	--	13 %	13 %
10 Insufficient time	37	5 %	3 %	3 %	11 %
11 Insufficient knowledge	2	--	--	--	--

Figure 6.21 *The extent to which DFE options (for which a specific barrier was mentioned) were prioritized (attributed with a success rate of 4, 5 or 6)*

In the foregoing we already distinguished 'initial barriers' from 'no-go barriers'. Figure 6.21 supports these findings. Typical initial barriers are 'conflict with functional requirements' and 'commercial disadvantage': despite these barriers however a considerable number of DFE options were still prioritized. Typical no-go barriers are 'no clear environmental benefit' (55% of DFE options with this barrier was rejected instantaneously), 'not perceived as responsibility' (70% of DFE options being rejected instantaneously) and 'no alternative solution is available' (24% of DFE options rejected instantaneously). Each of these three barriers were mentioned frequently (37 times or more); only one of the related DFE options was prioritized. Therefore, we may conclude that the top three influential barriers is 1) Not perceived as responsibility, 2) No clear environmental benefit and 3) No alternative solution is available. A fourth influential, yet far less frequently mentioned barrier is 'Not yet required by legislation'.

6.3.5 Conclusions

For external stimuli, internal stimuli and barriers the top three, most frequently mentioned factors, as well as the top three most influential factors is presented in Figure 6.22.

	External stimuli	Internal stimuli	Barriers
Most frequently mentioned	1. customer demands 2. government regulation 3. supplier developments	1. environmental benefit 2. cost reduction 3. image improvement	1. conflict with functional prod. requirem. 2. no clear environmental benefit 3. commercial disadvantage
Most influential	1. customer demands 2. government regulation 3. industrial sector initiatives	1. innovational opportunities 2. increase of product quality 3. new market opportunities	1. not perceived as responsibility 2. no clear environmental benefit 3. no alternative solution available

Figure 6.22 *Overview of the most frequently mentioned and most influential stimuli and barriers*

The influence of external stimuli versus internal stimuli

A comparison of the research results with regard to the relation between the success rates of DFE options and their external and internal stimuli leads to the conclusion that internal stimuli seem to have a greater influence than external stimuli on DFE decision-making in the companies investigated. This statement is based on the following summary of the above research results.

Despite the absence of external stimuli 172 of the 485 DFE options not motivated by any external stimulus were prioritized (35%); 128 of the 485 DFE options were even realized (26%). The results regarding internal stimuli show that notwithstanding the absence of internal stimuli, only 37 of the 257 DFE options not motivated by any internal stimulus were prioritized (14,4%); 35 of the 257 DFE options had been realized (13,6%). The fact that the percentages are lower in the case of internal stimuli supports the assumption that internal, rather than external stimuli are prerequisite for DFE.

Furthermore, 128 of the 183 DFE options with a success rate of 6 (70%) were realized despite the absence of external stimuli. This percentage is much higher than that for internal stimuli: only 35 of the 183 DFE options with a success rate of 6 (19%) were realized despite the absence of internal stimuli. These differences yet again emphasize the notion that internal stimuli, more than external stimuli, seem to influence the success rates of the suggested DFE improvement options do.

6.4 Influence of stimuli and barriers on success of DFE principles

The preceding Section 6.2.2 presented the numbers and types of stimuli and barriers mentioned for the DFE improvement options, categorized according to the DFE principle the option belongs to. The findings were presented subsequently in Figure 6.6, Figure 6.7 and Figure 6.8. The bar charts of these figures included the findings for all 596 DFE options, without distinguishing their degree of realization. However, it is interesting to assess what are the stimuli and barriers mentioned for DFE options, limiting ourselves to the DFE options that the SMEs studied prioritized (success rate 4, 5 or 6). This may yield additional insights in the types of stimuli and barriers that are particularly influential on the DFE decision making by SMEs.

6.4.1 Stimuli and barriers for prioritized DFE options

Three figures showing the stimuli and barriers mentioned for the selected group of 247 DFE options prioritized (with success rates 4, 5 or 6) are listed in Appendix C. The set up of these figures C.1, C.2 and C.3 is similar to the set up of Figure 6.6, Figure 6.7 and Figure 6.8, thus facilitating comparison.

Concentrating on the ***external stimuli*** (Figure C.1) the following becomes clear. First, as already mentioned, far from all prioritized DFE options are motivated by an external stimulus. Of course, the relative number of DFE options with an external stimulus is considerable higher in the group of 247 prioritized options than for the 596 DFE options altogether. Remarkably many external stimuli were mentioned for the DFE principles 4.1 Less/clean/reusable packaging, 5.2 Clean energy source, 5.5 No waste of energy/consumables, 6.1 High reliability and durability and 6.3 Modular/adaptable product structure. An assessment of the types of external stimuli recorded per category of DFE principle, leads to the conclusion that the mix of stimuli for each category of DFE principle in case of all 596 DFE options (Figure 6.6) is similar to the mix of stimuli per DFE principle for the selected group of 247 prioritized DFE principles (Figure C.1).

Focusing subsequently on the ***internal stimuli*** (Figure C.2) we find, conform our expectation, that almost all prioritized DFE options are motivated by at least one internal stimulus. Moreover, the number of internal stimuli per DFE option is often more than two. The number of internal stimuli per DFE option is remarkably high in case of the DFE principles 2.1 Reduction in weight, 3.2 Fewer production steps, 3.4 Less production waste, 5.1 Low energy consumption, 5.2 Clean energy source, 6.1 High reliability and durability, 6.3 Modular/adaptable product structure, 7.2 Remanufacturing/refurbishing and @.3 Integration of functions. This is similar to the equivalent picture derived from Figure 6.7. Also with respect to the types of internal stimuli that were mentioned per category of DFE principle, we do not find remarkable differences. Most categories of DFE principles are associated with a mix of types of internal stimuli, in Figure 6.7 as well as in Figure C.2. As mentioned before, the internal stimuli 'environmental benefit' and 'cost reduction' are dominant in almost all categories of DFE principles in both figures.

The ***barriers*** mentioned for all 596 DFE options were listed in Figure 6.8; the barriers mentioned for the selected 247 DFE options prioritized are shown in Figure C.3. Comparison of both figures leads to the conclusion that, as assumed, the number of barriers in each category of DFE principles is extremely low in Figure C.3 compared to the equivalent in Figure 6.8. Figure C.3 emphasizes that in many categories of DFE principles DFE options have been prioritized regardless of the barriers mentioned. Relatively many barriers are mentioned for DFE options of the DFE principles 1.1 Selection of clean materials, 1.4 Recycled materials, 2.1 Reduction in weight, 3.1 Clean production techniques, 4.1 Less/clean/reusable packaging and 6.1 High reliability and durability. The relative number of barriers is remarkably low in case of DFE principles 3.3 Low/clean production energy , 3.4 Less production waste, 4.3 Energy-efficient logistics, 5.1 Low energy consumption, 6.2 Easy maintenance and repair, 6.3 Modular/adaptable product structure, 7.2 Remanufacturing/refurbishing, 7.3 Recycling of materials and @.3 Integration of functions. This picture is similar to the picture derived from Figure 6.8.

6.4.2 Understanding the differences in success amongst DFE principles

If we finally compare the external stimuli (Figure C.1), internal stimuli (Figure C.2) and barriers (Figure C.3) perceived for the DFE improvement options prioritized, we can to a certain extent explain why, in the eyes of the SMEs studied, certain DFE principles are more preferred than others. Chapter 5 clearly showed these differences, and highlighted which DFE principles are more successful than others, in the sense that the DFE options belonging to the successful DFE principles systematically received higher success rates (4, 5 or 6) than the DFE options of other DFE principle types. The DFE principles that were most successful and the principles are listed again in Figure 6.23 below. The last column shows per DFE principle the percentage of DFE options prioritized compared to DFE options suggested in the action plans. The 'frequency of suggesting' refers to the number of times DFE options of this type had been suggested in the companies' DFE action plans. These ten DFE principles are not only prioritized, but also suggested very often, compared to the other, less successful DFE principles.

DFE principle	Description	Frequency of suggesting	% of DFE options prioritized
7.3	Recycling of materials	77	47%
6.1	High reliability/durability	38	45%
1.4	Recycled materials	20	45%
5.1	Low energy consumption	34	44%
7.2	Remanufacturing/refurbishing	19	42%
3.4	Less production waste	24	38%
3.1	'Clean' production techniques	20	38%
2.1	Reduction in weight	79	37%
1.1	'Clean' materials	72	28%
4.1	Less/'clean'/reusable packaging	27	26%

Figure 6.23 *The percentages of DFE options prioritized and the frequency of suggesting for the ten most successful DFE principle types*

In addition to the successful DFE principles as listed in Figure 6.23 above, we should mention the DFE principles that had not been suggested often in the DFE action plans, but were prioritized relatively often nevertheless. These successful but less often suggested DFE principles are listed in Figure 6.24 below.

DFE principle	Description	Frequency of suggesting	% of DFE options prioritized
3.2	Few production steps	5	60%
3.3	Low/'clean' production energy	10	60%
6.2	Easy maintenance/repair	12	58%
6.3	Modular/adaptable structure	9	56%
4.3	Energy efficient logistics	8	50%
3.5	Few/'clean' production consumables	9	44%

Figure 6.24 *DFE principles that were prioritized relatively often, though they had not been suggested frequently*

On the opposite, the least successful DFE principles, meaning that only 25% or less suggested DFE options were prioritized, were the DFE principles 1.2 Renewable materials, 5.4 Clean consumables, 6.4 Classic design, 7.1 Reuse of product and @.4 Functional optimization.

As expected we find that for almost all successful DFE principles external stimuli were mentioned; for the least successful DFE principles however hardly any external stimuli were perceived. With respect to the internal stimuli we find that about two stimuli were recorded for almost all prioritized DFE options of the most successful DFE principle types. For the least successful DFE principles some internal stimuli were mentioned as well; however, they were strongly concentrated on a limited set of DFE options of the specific DFE principle type.

Focusing on the barriers for the DFE options prioritized, as presented in Figure 6.8 and Figure C.3, we find that relatively few barriers were mentioned for the successful DFE principles. An exception to this is DFE principle 6.1 High reliability and durability: for 8 of the 17 prioritized DFE options in this category a barrier was mentioned, mostly of the type 'conflict with functional product requirement'. Obviously this is only an initial barrier, overcome by the relatively vast amount of internal as well as external stimuli mentioned for this DFE principle in particular. Surprisingly we do not find any barriers mentioned for the least successful DFE principles in Figure C.3. This is partly due to the very limited amount of DFE options prioritized altogether in these categories. Figure 6.8 though shows that relatively many DFE options belonging to the least successful categories of DFE principles are subject to at least one barrier.

The research results above support our expectation that the success of a specific DFE principle is reflected by a relatively high number of external as well as internal stimuli. Furthermore, they are associated with relatively few barriers that in Section 6.4 moreover were characterized as 'initial' barriers.

.4.3 Stimuli and barriers for prioritized DFE options new to the company

We can even go one step further and analyze the motivation of the SMEs studied to prioritize the suggested DFE options that were completely new to them. With respect to each of the 596 DFE improvement options the 'newness' was assessed during the telephone interviews with the SME's representatives. Figure 3.6 in Chapter 3 showed the three categories of newness distinguished.

It is assumed that the influence of stimuli is strongest and the impact of barriers lowest for those DFE improvement options that the SME's prioritized in spite of the fact that they were completely new for the companies involved: these companies had never considered them before (newness 3). The Figures C.4, C.5 and C.6, included in Appendix C, reveal what are subsequently the external stimuli, internal stimuli and barriers perceived for this selected group of 51 DFE improvement options. The DFE options selected belong mostly to the DFE principles 1.1 Selection of clean materials, 2.1 Reduction in weight, 4.1 Less/clean/reusable packaging, 7.2 Remanufacturing/refurbishing and 7.3 Recycling of materials (each listing at least three prioritized options). Not to our surprise, each of these five very successful DFE principles was already earmarked as a successful DFE principle, included in Figure 6.23.

Figure C.4 reveals that considerable amounts of external stimuli were only mentioned with respect to DFE principles 1.1 Selection of clean materials, 4.1 Less/clean/reusable packaging, 6.3 Modular/adaptable product structure and 7.3 Recycling of materials. As seen before, the number of internal stimuli visible in Figure C.5 is, in contradiction to the number of external stimuli, very high altogether. Figure C.6 shows that even some of the 51 selected DFE options (prioritized and new) are associated with a barrier. The barriers concern, with only one exception, initial barriers of the types 'conflict with functional product requirement' or 'commercial disadvantage'. The fact that the specific DFE options were nevertheless prioritized can be explained by the high number of internal stimuli mentioned simultaneously. For ten DFE principles one barrier was mentioned; for all these ten categories at least one internal stimulus was perceived as well. However, external stimuli were only mentioned with respect to five of the ten DFE principles. This again supports our assumption that internal stimuli influence the DFE related decision-making in product development in SMEs to a higher extent than external stimuli do.

6.5 Conclusions

6.5.1 Reflecting on hypothesis 1.A

Hypothesis 1.A: Regarding the application of DFE in SMEs, the actual influence of internal stimuli on the success rate of DFE principles is stronger than the influence of external stimuli.

This assumption, that opposes the traditional line of thinking in environmental management literature, was raised in Chapter 4 as a result of an analysis of the available theoretical perspectives on factors that (de)motivate the application of design for environment in large as well as small companies.

To begin with, the frequency of mentioning external versus internal stimuli was assessed in Section 6.2.1. In case of external stimuli 130 stimuli were mentioned for 111 of the 596 DFE options; regarding internal stimuli, as many as 795 stimuli were mentioned for 339 DFE options. We can conclude that many more internal stimuli were mentioned than external stimuli; moreover, internal stimuli were mentioned for three times as many DFE options than external stimuli. However, it is not justified to draw the conclusion that internal stimuli are more influential than external stimuli, solely because they differ considerably in their frequencies of mentioning.

A more accurate approach is to assess the relation between the stimuli perceived and the success rate of the specific DFE improvement option for which the stimuli were mentioned. Section 6.3.1 learned that, in spite of the absence of external stimuli, 172 of the 485 DFE options not motivated by any external stimulus (35%) were nevertheless prioritized (success rate 4, 5 or 6); 128 of the 485 DFE options (26%) were even realized (success rate 6). Regarding the internal stimuli the results show that notwithstanding the absence of internal stimuli, only 37 of the 257 DFE options not motivated by any internal stimulus were prioritized (14,4%); 35 of the 257 DFE options were realized (13,6%). The fact that the percentages are lower in case of internal stimuli gives support to the assumption that internal stimuli are prerequisites for DFE more than external stimuli are.

Further, 128 of all 183 DFE options with success rate 6 (70%) were realized in spite of an absence of an external stimulus. This percentage is much higher than its equivalent with respect to internal stimuli: only 35 of the 183 DFE options with success rate 6 (19%) were realized in spite of an absence of an internal stimulus. This difference again emphasizes the notion that internal stimuli seem to influence the success rates of the suggested DFE improvement options more than external stimuli.

Special attention was given in Section 6.4 to a small selection of 51 DFE improvement options that were prioritized in spite of the fact that they were new to the company. Figure C.6 in Appendix C revealed quite unexpectedly that even some of these DFE options were associated with a barrier. However, their success can be explained by the high number of internal stimuli recorded for each of the ten DFE principles associated with a barrier. The fact that external stimuli were mentioned for only five of these ten DFE principles corroborates our assumption that internal stimuli are more prerequisite for DFE success than external stimuli.

Considering the foregoing set of research findings we can conclude that they support hypothesis 1.A. DFE decision-making in the companies studied would seem to be influenced more by internal than external stimuli: internal stimuli seem to have had a greater impact on the success rate of the DFE improvement options than the external stimuli.

Does this mean that the ultimate objectives of DFE will be achieved without stronger external stimuli? The answer to this is thought to be in the negative. The companies seem to have generally realized those DFE options that match their more traditional commercial values in product development. The most influential internal stimuli found were 'innovational opportunities', 'increase of product quality' and 'new market opportunities'. The study shows that environmental quality is often seen as an element of product quality; moreover, environmental aspects can function as an impetus for product innovation. This is in line with the empirical findings of Smith, Roy and Potter (1996). Their study was based on a series of interviews with senior management, marketing and technical design staff in sixteen British, American and Australian companies which had deliberately or incidentally introduced significant environmental improvements into the design of their products. They found that the companies studied did not set out to produce a 'greener' product. The companies took environmental factors into account 'in pursuit of commercial aims'. However, implementing DFE means more than only realizing DFE options with challenging commercial opportunities. In order to stimulate companies to do so, strong and consistent external stimuli are essential.

6.5.2 Reflecting on hypothesis 1.B

Hypothesis 1.B: Of all the internal stimuli that motivate an SME to implement DFE improvements, the personal environmental commitment of the company's owner-manager is the most influential factor.

The empirical findings do not support hypothesis 1.B. The analysis of the relation between internal stimuli mentioned for DFE options and the success rates of these options showed that the internal stimulus of 'personal environmental commitment' was not perceived in particular for the options that were prioritized. Many DFE options were rejected despite the fact that the respondent was convinced of its environmental benefit.

These findings are similar to a conclusion drawn by Smith et al. (1996) on the basis of their study on sixteen companies that were proactive in the field of DFE. They found that improvements in environmental performance only became a significant competitive factor once high levels of product performance, quality and value were attained. We may conclude that a DFE improvement option only stands a chance if it is supported by stimuli other than the expected environmental benefit alone.

6.5.3 Reflecting on hypothesis 1.C

Hypothesis 1.C: The participants in the IC EcoDesign project will reject DFE improvement options that are susceptible to the barriers 'insufficient complementarity', 'lack of interesting technological options' and 'insufficient appropriability'

Hypothesis 1.C reflects the expectation that DFE improvement options must meet at least three requirements in order to have a chance of being realized. First, a DFE option must be complementary to the product requirements already stated. This prerequisite is embodied in the barrier characterized as 'this option results in a conflict with functional product requirements'. Second, a DFE option is only prioritized if technological options (alternative solutions for the related environmental problem) already exist, or if the company is interested in developing the technology itself. This prerequisite is translated into the barrier 'there is no technological alternative solution available' and 'this option does not embody interesting innovation opportunities'. The third prerequisite for a DFE option to be prioritized is called 'appropriability': the DFE option must result in a commercial advantage that the company can appropriate. This condition is represented by the barrier 'the DFE option results in a commercial disadvantage'.

Do the empirical results match the expectation mentioned above? First of all, the research results show that of all the barriers that were recorded, the barrier of 'this option results in a conflict with functional product requirements' was by far the most frequently mentioned. However, Figure 6.13 in Section 6.3.1 made it quite clear that this barrier can be characterized as an 'initial barrier' instead of a 'no-go barrier': many DFE improvement options for which this barrier was mentioned were still realized. This implies that with respect to the prerequisite of 'complementarity', hypothesis 1.C is not supported by the empirical findings.

The situation is quite different with regard to the second prerequisite 'technological options'. Figure 6.13 in Section 6.3.1 led to the conclusion that the barrier 'there is no technological alternative solution available' can be characterized as a 'no-go barrier' in the sense that the DFE options associated with it are rejected or postponed for several years. However, the companies studied failed to even mention the barrier described as 'this option does not embody interesting innovation opportunities'. This implies that we cannot draw any conclusions on this type of barrier. Hypothesis 1.B is only supported

by empirical findings in the sense that a prerequisite for the realization of DFE improvement options in the companies studied is the availability of suitable technological alternative solutions.
Finally, Figure 6.13 in Section 6.3.1 led to the conclusion that the barrier 'the DFE option results in a commercial disadvantage' was mentioned very frequently. However, it is apparently only an 'initial barrier' if we look at the number of DFE options that were realized despite perception of this barrier. It is definitely not a 'no-go barrier'. 'Appropriability' is therefore not a prerequisite for the realization of suggested DFE improvement options. This implies that the research results do not support hypothesis 1.B with regard to the third prerequisite of 'appropriability'.

Quite unexpectedly, two other barriers were apparently prerequisite for the realization of suggested DFE improvement options. The research results presented in Section 6.3.1 show that these other 'no-go barriers' are the barriers described as 'we doubt the environmental benefit of the DFE option', plus the barrier 'we do not feel responsible for realization of the DFE option'. None of the DFE improvement options associated with either of these barriers were prioritized. Nearly all DFE options with one of these barriers were rejected. The two prerequisites thus identified can be described as 'a conviction of the environmental significance of the DFE option' and 'corporate commitment regarding the realization of the DFE option'.

We conclude that the empirical findings do not support hypothesis 1.C. Insufficient complementarity and appropriability are apparently only 'initial barriers': the fact that they were mentioned did not automatically block realization of the DFE improvement concerned. Only the availability of proper alternative technological solutions was a 'no-go barrier': DFE options associated with this barrier are either rejected or postponed for several years. In addition to this barrier, two others (not mentioned in hypothesis 1.C) are prerequisite for the realization of a DFE option. These two barriers can be described as 'we doubt the environmental benefit of the DFE option', and 'we do not feel responsible for realization of the DFE option'.

The mismatch between hypothesis 1.C and the empirical findings of this study could be due to how the capability theory was operationalized in order to construct hypothesis 1.C. In the process of translating certain elements of the capability theory into research questions for this study, the theory may have been interpreted too freely. This might have been because the capability theory has not yet been properly operationalized; this was already suggested by Den Hond (1996).

6.5.4 Answering research question A

The aim of this chapter has been to answer the first of the two central research questions for this study, elaborated into research model A. This initial research question was: *Can we explain why certain DFE principles are more successful than others?*

Chapter 5 showed that there are indeed considerable differences in success among the 33 DFE principles distinguished. The research results subsequently described in the above led to the conclusion (which supported our expectations) that the success of a specific DFE principle is reflected by a relatively high number of external as well as internal stimuli. Furthermore, successful DFE principles are associated with relatively few barriers; these were characterized as 'initial' barriers in Section 6.4.

In conclusion, Figure 6.25 shows which external stimuli, internal stimuli and (absence of) barriers seem to have the most influence in DFE decision-making. It also lists the ten most successful DFE principles.

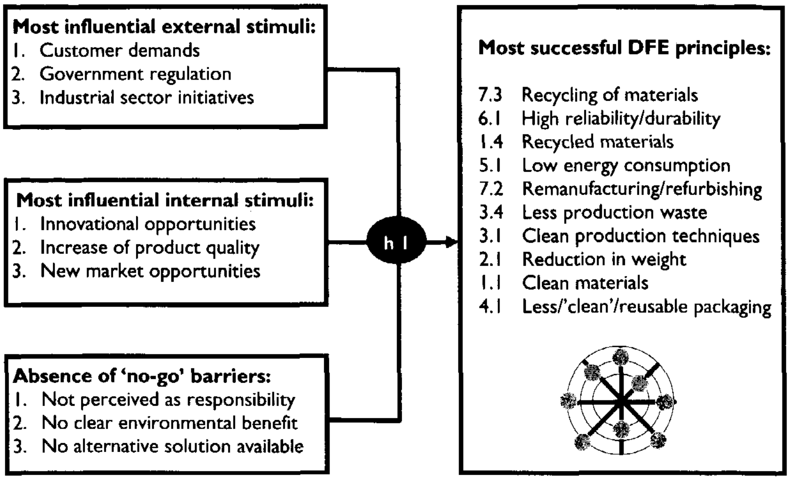


Figure 6.25 *Research model A with hypothesis 1, incorporating the most influential stimuli and barriers, plus the ten most successful DFE principles, based on the empirical findings of this study*

Understanding the companies' DFE performance

Chapter 7 focuses on research question B: How can we explain the differences in DFE performance among the SMEs that participated in the IC EcoDesign project? It first presents the empirical research data on the characteristics incorporated in research model B. Subsequently, the relationship between the explanatory characteristics and DFE performance is analyses. In conclusion, this chapter reflects on the hypotheses 3, 4, 5 and 6. Hypothesis 2, also incorporated in research model B was already reflected upon at the end of Chapter 5.

Introduction

How can we explain the assumed differences in DFE performance among the SMEs participating in the IC EcoDesign project? This question is the fundament of research focus B of the study reported on in this thesis. Chapter 5 already presented the results of these companies in terms of DFE performance, showing a considerable difference from one company to another.
This chapter will try to explain the reason for this. The approach used in this analysis is visualized in research model B in Figure 7.1 below. This model distinguishes four groups of explanatory variables covering characteristics which are related to the company, product, respondent and intervention. Furthermore, the latent dependent variable of DFE performance is operationalized into three scales of measurement; DFE focus, DFE result and DFE learning. A range of statistical cluster analyses, reported in Chapter 5, taught us that each of the three DFE performance indicators can be aggregated into one measurement scale.

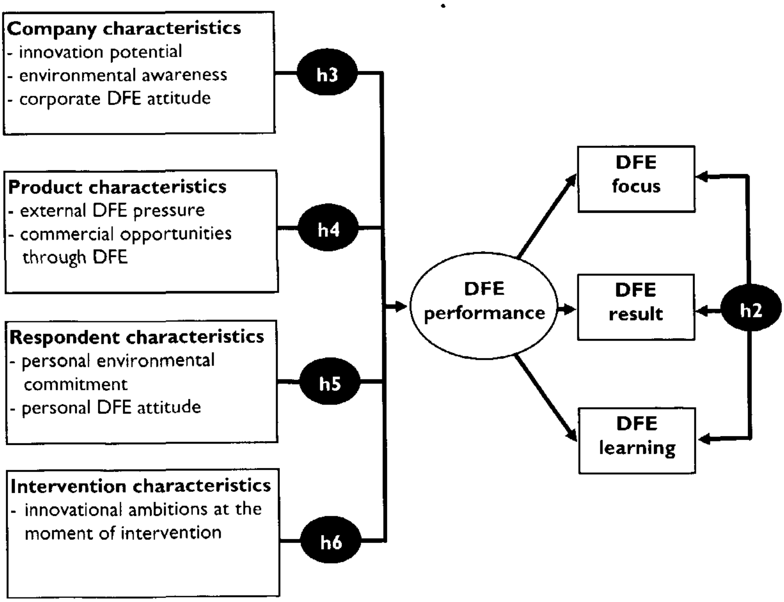


Figure 7.1 *The (partial) research model B with hypotheses 2, 3, 4, 5 and 6, each consisting of various sub-hypotheses*

Section 7.2 first presents the empirical research data on the characteristics incorporated in research model B. Subsequently, Section 7.3 analyses the relationship between the explanatory characteristics and DFE performance. In conclusion, this chapter will reflect on the subsequent hypotheses 3 (Section 7.3.2), 4 (Section 7.3.3), 5 (Section 7.3.4) and 6 (Section 7.3.5). Hypothesis 2, also incorporated in research model B in Figure 7.1, was already reflected upon at the end of Chapter 5.

7.2 Explanatory variables

7.2.1 Company characteristics

Measurements were taken of a wide range of explanatory variables in order to relate the DFE performance of the participating companies to some company characteristics. These were then used to form an image of the group of SMEs that participated in the research. The exact figures that led to the following overview are listed in table D.1 in Appendix D. Appendix B contains the original questions.

With regard to ***size*** of the participating companies, those studied all belong to the SME sector. This was defined in the IC EcoDesign project as a company which, with a few exceptions, employs a maximum of 200 workers. Of all 77 companies studied, 94% employ up to 200; 60% employ 50 or less; 25% employ a maximum of 10.
As expected, the ***industries*** best represented were metal products, machinery, wood and furniture, followed by rubber and synthetics, electronics and the textile industry. Unexpectedly, the car industry was represented by only one company.
About 30% of the companies have no facilities for in-house ***product development***. The other 70% do employ in-house product developers, of which almost 38% employ one or two in-house product developers, and 32% three or more. About 55% of the companies stated that they always drew up the specifications for their products themselves; the others gave answers ranging from 'not always' to 'never' (on a 'gliding scale'). Likewise, the majority (75%) sell end products; 14% are suppliers for other industries. About 80% of the companies regard 'product development' as one of their core activities, of which 60% develop, produce, assemble and sell their products and 10% focus on development, assembly and sales only. Looking carefully at these figures we can conclude that approximately three-quarters of the companies studied may be regarded as 'product developers'.

Most companies regard themselves as ***innovative***: about 5% say they are less or much less innovative than their core competitors; about 30% say they equal their competitors and about 55% claim to be more or much more innovative than their competitors. R.G. Cooper suggested a somewhat more objective method for measuring the innovativeness of companies (Cooper, 1984). He suggests two indicators for innovativeness, the percentage of sales and the percentage of profits raised by the products developed in the past five years. Also by means of these indicators we see that the companies studied are considerably innovative: more than 50% claim that more than half of their sales, and more than half of their profits are obtained thanks to the products they have developed since 1991.
Many of these companies are ***relatively young*** in terms of the year in which they started to develop their own products: 43% have only been developing products since 1990 or even more recently. Furthermore, table D.1 in appendix D shows us that about 40% uses ***written procedures*** like a check-list for product development. About 60% of the companies studied claims to have a ***quality system*** which, in half of them, is formally certified. This leads to the conclusion that a considerable number of companies would seem to be well organized.

Shifting our focus from the activities of these companies in general towards their environmental initiatives, table D.2 in Appendix D shows the following. A substantial number of these companies have set up a sort of ***environmental management system*** (EMS), ranging from a formal EMS (12%) to an informal, partial EMS (30%). A small number of companies (6%) have entered into a so-called ***environmental covenant***, which is a 'gentlemen's agreement' between government and industry to take certain measures to reduce a specific environmental problem. As many as 20% of the companies studied were completely unaware of the existence of these environmental covenants.
When the companies were asked to ***compare*** their environmental initiatives with those of their competitors, most companies regarded their environmental efforts as comparable with those of their competitors (54%). About 30% estimated their own efforts as stronger. Only 3% felt that their

competitors' environmental efforts were bigger than their own. However, these figures are apparently based on guess-work, since only 5% of the companies had performed at least one environmental benchmark study in the past five years.

The companies were also asked for their opinion on and experience with ***design for environment***, referred to as EcoDesign. Of all companies studied, 75% had had no or very little experience with EcoDesign before embarking on the IC EcoDesign project. The EcoDesign experience reported by the other companies focused on the substitution of 'conspicuous' materials with alternatives with a lower environmental impact.
Table D.3 in Appendix D shows that most companies regarded EcoDesign as an ***opportunity*** rather than a threat at the moment the monitor took place. EcoDesign was recognized by some 60% of the companies for its marketing potential. Some companies saw EcoDesign as a cost-neutral activity. However, the majority regarded EcoDesign as an initial investment, the costs of which would be recovered in the medium to long-term.
External parties perceived to be most concerned about EcoDesign were government, suppliers and trade associations. However, the parties which actually stimulated them to implement EcoDesign were government, industrial customers and the end users of the product. Only 30% of the companies agreed that environmental legislation made EcoDesign necessary in their business.
Questioned about attitude towards EcoDesign in various company departments, the companies generally answered positively: the ***attitude of their departments*** was 'involved' rather than 'rejecting'. It was hardly surprising to see that the most involved company departments were the environmental department (if it existed), the product development department and the management.

Table D.4 in Appendix D shows that the two most important ***motives for participation*** in the IC EcoDesign project were the wish to increase the quality of specific products, and the importance of anticipating future developments. The third, strong motive was that EcoDesign was seen as an important aspect of product innovation. The fourth being the company representative's personal responsibility he felt for the environment. The search for environmentally harmless alternative materials or components, and supply chain pressures were also strong motivations.

7.2.2 Product characteristics

What kind of products were put forward by the companies as subjects for the Environmental Innovation Scan? Table D.5 in Appendix D lists a selection of the product characteristics selected as the second group of explanatory variables. The original questions are included in Appendix B. These form the basis for the following short description of the characteristics of the selected products.

It must be pointed out first of all that the ***products varied strongly*** in terms of functional and material product characteristics like their function, dimensions, materials, production techniques, users, etc. For example: the group of products included such diverse products as packaging and a coach. The products' functional life time varied quite substantially too: about half the products last between 6 months and 10 years; the other half from 11 to 75 years. This is a consequence of the broad scope of the IC EcoDesign project which did not focus on one branch of industry only. Hence, the environmental impact of the products varied to a large extent as well (both in terms of character and significance of the impact).
About 35% of the products are sold only in the Netherlands. Most products are sold both in the Netherlands and on export markets. The most frequent ***types of markets*** are the consumer market and the industrial market. Only 10% is intended mainly for the institutional market.
In terms of the ***commercial life cycle*** of the product categories studied, one-third had only recently been introduced (introduction stage), one-third had growing market shares (growth stage), one-third had stagnating market shares (maturation stage). Only two products showed a decreasing market share (decline stage).

A second set of explanatory variables clustered in the group of product characteristics, relates to the company's perceived ***external pressure*** to apply EcoDesign to their specific product. Table D.6 in Appendix D lists a selection of relevant empirical data. These data lead to the conclusion that there is only a limited amount of external pressure to apply EcoDesign to the products. Only 20% of the companies were asked by their customers to sign a declaration that their products contained no specific hazardous materials. Only 9% promised their customers that they would take back their products after their functional lifetime. Environmental covenants between government and the companies' branches of industry were mentioned by only 12% of the companies. The branches of industry of only 8% of the companies had been subject to pressure from an environmental action group. The empirical data in table D.6 show that the companies feel very little motivation to apply EcoDesign to their products as a result of external pressure from their particular branch of industry, the retail sector, consumer organizations, environmental action groups, suppliers or competitors. On average, only very modest pressure was felt from the government, the customers and the end users of their products. The most important motives given as the reason for participation in the project were the wish to increase the (environmental) quality of the products involved, and to help them act in advance of legislative developments.

The third set of variables belonging to the group of product characteristics relate to the ***commercial opportunities*** EcoDesign offers in connection with the product concerned. A selection of empirical data is given in table D.7 in Appendix D. The companies were asked to indicate the extent to which they thought the cost structure for their product would be influenced by EcoDesign. According to the companies studied, on average EcoDesign has little influence on the costs of disposal, production costs and packaging costs. However, the answers given by these companies do show a considerable variance on the measurement scale from 1 (costs increase strongly) to 5 (costs decrease strongly). The costs incurred in taking a product back and those involved in EcoDesign-related R&D are generally thought to increase slightly. On the other hand, the average outcomes for the costs related to the purchase of materials and components and transport costs show that the companies generally think that these costs will decrease thanks to EcoDesign. Again, there is an enormous variation in the answers given by the different companies.

7.2.3 Respondent characteristics

The third group of variables measured to help explain the difference in DFE performance includes a selection of characteristics related to the respondent involved. This is the person who had been involved in the IC EcoDesign project from the start. All but two of them were interviewed for the research reported in this thesis.

The data given in table D.8 in Appendix D show that the respondent was usually the ***owner-manager*** of the company or the head of the product development department. The respondent was never an environmental manager. The respondents characterized their ***attitude*** towards EcoDesign as 'critical' in 16% of the cases, 33% called themselves 'reactive'; an 'active' attitude was mentioned by 45% of the respondents, while 8% regarded themselves as 'very active'.
The average respondents' ***appreciation*** for the IC EcoDesign project was 7.0 when measured on a scale of 1 (negative) to 10 (positive). They were also asked to indicate the extent to which they thought the IC EcoDesign project was relevant and recommendable to other companies. The average score was 4.0 on a scale of 1 (not recommendable) to 5 (highly recommendable). This implies that most respondents were positive about the set-up and results of the IC EcoDesign project.
The respondents were also asked how much their personal environmental commitment had played a role in their decision to participate in the IC EcoDesign project. A total of 80% said their ***environmental commitment*** was one of the reasons for participation. This was a moderately strong argument for 30% of the respondents; it was a considerably strong argument for 31% and a strong argument for 18%.

7.2.4 Intervention characteristics

The fourth group of explanatory variables consists of characteristics related to the intervention itself. The first intervention characteristic was the time when the IC consultant performed the Environmental Innovation Scan in the company. That was a time when the company's 'innovational ambitions' regarding the selected product could be either high or low. The expectation is that the higher the so-called momentary ***innovational ambitions***, the higher the resulting DFE performance. The data showed that for about half the products the momentary innovational ambitions were relatively high: at the moment the product was environmentally scanned it was either being redesigned already or would be redesigned in short term. For the other half, innovational ambitions were low due to the fact that the product had only recently been developed or redesigned or because the company had no desire to invest more in that specific product for a variety of reasons. An additional indication of the company's momentary innovational ambitions was derived from the reason given by the company for selecting the product in question. There were various reasons for this but the most frequently mentioned were:

- The company expected market opportunities if the product was environmentally improved;
- The product was to be redesigned anyway;
- The product was the company's only product;
- The environmental problems with respect to the selected product seemed to be relatively clear.

The fact that the product fell under environmental legislation seemed to play a minor role. The fact that market opportunities were mentioned more than environmental legislation is in line with the findings formulated in Chapter 6: in practice the demands of customers and end users are more influential than environmental legislation. If one of the reasons stated was that the product was up for redesign anyway, the momentary innovational ambitions are regarded as high. This reason was given by only 20% of the companies.

Another intervention characteristic relates to the person who advised the company on the topic of EcoDesign, the ***IC consultant***. A total of 22 persons (IC consultants and IC assistant consultants) carried out the Environmental Innovation Scans in the 77 companies studied in this thesis. The number of scans per persons varied considerably from a minimum of one scan up to a maximum of seven scans per IC consultant. Furthermore, the number of Innovation Centres that participated in the IC EcoDesign project was 17. Again we see a variance in the number of scans executed per Innovation Centre, ranging from one to eight. The variances mentioned above can be explained as follows. the first reason being that the EcoDesign targets (the number of companies to be included in the project) per Innovation Centre varied, depending on the number of companies that belonged to the target group for the IC EcoDesign project in the specific region. The second reason being that the commitment and enthusiasm for the project varied considerably amongst the IC consultants themselves, resulting in a variation in the number of companies consulted.

7.3 Understanding the design for environment performance in SMEs

7.3.1 Introduction

The intention of this chapter is to assess whether the differences in DFE performance among SMEs can be explained (in part) by means of a specific set of explanatory characteristics, clustered into four groups: company, product, respondent and intervention characteristics. Four sets of hypotheses (3.A, 3.B, 3.C, 4.A, 4.B, 5.A, 5.B and 6) were formulated in Chapter 4 specifying the relationship between each of the four groups of characteristics and the companies' DFE performance as a result of the IC EcoDesign project. The characteristics are referred to as the explanatory variables.
The latent dependent variable is the company's DFE performance, specified as:

- the company's ***DFE focus***: the number and type of DFE improvement options the company prioritized;
- the company's ***DFE result***: the actual changes in the product, packaging or process design, operationalized by means of five indicators 'DFE score', 'DFE project score', 'DFE design impact', 'DFE result opinion' and the aggregated 'DFE result scale';
- the company's ***DFE learning***: the extent to which a company is able to use DFE individually in future product development, operationalized by means of five indicators: 'DFE objectives', 'DFE external involvement', 'DFE awareness', 'DFE specification' and the aggregated 'DFE learning scale'.

Assessing the relationship between the explanatory variables and the dependent variables one by one was done by means of correlation analyses, a bivariate statistical analysis technique. The correlation coefficients calculated ('Spearman's r' in the case of ordinal explanatory variables and '_' in the case of nominal explanatory variables) are listed in the figures presented in this chapter.

One of the three aspects of DFE performance, ***DFE focus, was not included*** in this analysis.
In addition to a company's DFE result and DFE learning, research model B shows that DFE performance also encompasses a third element: the company's DFE focus. Chapter 5 presented the measurement results on all three elements of DFE performance. A detailed analysis made it clear that the companies could be clustered according to their specific DFE focus. A statistical cluster analysis made on the basis of Ward's method led to eight company clusters being distinguished, based on their more-or-less similar DFE focus. An additional result (also presented in Chapter 5) was that the indicators DFE focus, DFE result and DFE learning were correlated; certain DFE focus clusters consist of companies with relatively high scores for DFE result and DFE learning (see Section 5.6, reflecting on hypothesis 2).
One intriguing question that followed was: Can we explain this distinction in eight so-called 'DFE focus clusters' by means of certain company or product characteristics? Do companies form clusters because they have certain characteristics in common? An initial effort to answer this question was made by means of statistical analyses, as was the case for DFE result and DFE learning, the other two elements of DFE performance. This analysis showed us that statistical techniques were generally not suitable for assessing the relationship between a company's characteristics (company, product, respondent or intervention characteristics) and its DFE focus. The reason for this is simply because of the enormous difference in the type of company studied. This was due to the fact that the IC EcoDesign project had not focused on specific branches of industry. The number of cases looked at in the study was not large enough to overcome this problem. A group of 77 companies is insufficient to yield reliable analysis results. This is a problem given that the dependent variable 'DFE focus cluster' is a nominal variable; it was not problematic in respect of the indicators for DFE result and DFE learning (these were ordinal (pseudo-metric) variables). This question could be studied in greater detail in future research. The strategy we recommend is to focus the study on a limited number of branches of industry in order to obtain more homogeneous groups of companies.

The following four sections present the results of the analyses, and subsequently assess the relation between a company's DFE result and DFE learning and the company, product, respondent and intervention characteristics of the companies involved. Whenever the term 'DFE performance' is used here it refers to a company's DFE result ***plus*** DFE learning. The codes just behind the variables' description refer to the original questionnaire, included in Appendix B.

7.3.2 Company characteristics; reflecting on hypothesis 3

With respect to the relation between company characteristics and company DFE performance, hypotheses 3.A, 3.B and 3.C were formulated as operationalizations of hypothesis 3 in Chapter 4. These three sub-hypothesis will subsequently be reflected upon in the following.

Hypothesis 3.A Companies with a high innovative potential have a higher DFE performance than less innovative companies.

Since it is difficult to measure a company's innovativeness, this variable has been operationalized by means of four sets of indicators. Figure 7.2 shows the correlation coefficients between these four sets of indicators and DFE performance indicators. The correlation coefficient has been set against a gray background if it is 0.25 (+ or -) or more: this indicates a considerable correlation between the two variables. If the coefficient between 0 and 0.25 (+ or -) is called 'weak'; if it is between 0.65 and 1.00 (+ or -) it is regarded as 'high'.

	DFE Result					**DFE Learning**				
	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE result scale	DFE objec-tives	DFE involvem. extern	DFE aware-ness	DFE specifi-cation	DFE learning scale
Innovativeness A:										
Experiments product launches, v028, r	0.02 (72)	0.16 (72)	0.15 (75)	**0.26 (74)**	0.18 (71)	0.01 (54)	0.21 (67)	**0.27 (72)**	0.22 (48)	**0.35 (37)**
Company searches for new ideas, v029, r	0.03 (72)	0.09 (72)	0.05 (75)	**0.25 (74)**	0.11 (71)	0.01 (54)	0.21 (67)	**0.26 (72)**	0.23 (48)	**0.34 (37)**

Company spends much on R&D ,v030,r	0.17 (71)	0.18 (71)	0.22 (74)	0.24 (73)	**0.27 (70)**	0.18 (53)	**0.25 (66)**	0.18 (71)	0.16 (47)	**0.41 (36)**
Company stimulates creativity, v031, r	0.04 (72)	0.09 (72)	0.09 (75)	0.16 (74)	0.07 (71)	0.06 (54)	0.16 (67)	0.13 (72)	0.06 (48)	0.22 (37)
Company is not afraid of risk taking, v032, r	0.17 (72)	0.20 (72)	**0.26 (75)**	0.15 (74)	0.22 (71)	0.07 (54)	0.06 (67)	0.10 (72)	**0.26 (48)**	0.23 (37)
Encourages employ. initiatives, v033, r	0.04 (72)	0.03 (72)	-0.04 (75)	0.07 (74)	0.07 (71)	0.08 (54)	0.21 (67)	0.06 (72)	**0.29 (48)**	0.20 (37)
Application newest technologies, v040, r	0.03 (72)	0.08 (72)	-0.02 (75)	0.03 (74)	0.11 (71)	0.22 (54)	0.24 (67)	0.16 (72)	0.13 (48)	**0.35 (37)**
Extensive market knowledge, v041, r	0.16 (72)	0.15 (72)	-0.04 (75)	-0.13 (74)	0.10 (71)	-0.04 (54)	-0.15 (67)	-0.05 (72)	-0.01 (48)	-0.16 (37)
Innovativeness B:										
Product has unique features, v034, r	**0.26 (72)**	**0.38 (72)**	**0.33 (75)**	**0.32 (75)**	**0.44 (71)**	0.24 (54)	**0.26 (67)**	0.17 (72)	0.21 (48)	**0.32 (37)**
Higher quality than competitors, v035, r	0.08 (72)	0.10 (72)	0.07 (75)	0.03 (74)	0.08 (71)	-0.06 (54)	0.06 (67)	0.11 (72)	-0.01 (48)	0.06 (37)
Me-too products, v036, r	-0.13 (71)	-0.13 (71)	-0.06 (74)	-0.12 (73)	-0.19 (70)	-0.21 (53)	-0.34 (66)	-0.16 (71)	-0.18 (47)	**-0.34 (36)**
Competition driven by cost price, v037, r	-0.03 (72)	-0.07 (72)	-0.04 (75)	0.02 (74)	-0.01 (71)	0.02 (54)	-0.01 (67)	0.05 (72)	-0.12 (48)	-0.03 (37)
Highly innovative products, v038, r	0.21 (72)	0.12 (72)	0.17 (75)	0.14 (74)	**0.25 (71)**	**0.31 (54)**	**0.31 (67)**	0.00 (72)	0.19 (48)	**0.33 (37)**
Very advanced products, v039, r	0.02 (72)	0.09 (72)	0.06 (75)	-0.02 (74)	0.13 (71)	0.07 (54)	0.02 (67)	0.02 (72)	0.05 (48)	0.13 (37)
Innovativeness C:										
Self-estimation of innovativeness,v042, r	0.18 (69)	-0.02 (69)	0.05 (72)	-0.07 (71)	0.08 (68)	0.09 (52)	0.11 (64)	0.02 (72)	0.09 (46)	0.18 (36)
Innovativeness D:										
% of sales due to new products, v048, r	0.10 (60)	0.09 (60)	-0.15 (62)	-0.02 (62)	0.08 (60)	0.03 (44)	-0.24 (56)	0.04 (59)	-0.03 (43)	-0.12 (33)
% of profits due to new products, v049, r	0.15 (58)	0.02 (58)	-0.11 (60)	-0.10 (60)	0.06 (58)	-0.08 (43)	**-0.29 (54)**	-0.04 (57)	-0.05 (41)	**-0.27 (32)**

Figure 7.2 *Correlation coefficients (Spearman's r or η) between four sets of indicators for a company's innovativeness and its DFE result and DFE learning*

Innovativeness A

The first assumption was that DFE performance would be the highest if a company experiments, searches actively for new product ideas, spends a large amount on R&D, stimulates the creativity of its employees, takes risks, encourages the employees to take initiatives, is not a follower in the market, applies the newest technology, and is aware of the customers' wishes, and has an innovative attitude. Figure 7.2 shows that most variables are weakly correlated (with a Spearman's r or η between 0 and 0.24). However, we see a considerable correlation in respect of three of the eight indicators for innovativeness mentioned above: DFE performance seems to be relatively high in companies that claim to experiment, search actively for new product ideas and spend a large amount on R&D.

Innovativeness B

A second set of indicators for innovativeness was defined as: products offering unique features are developed by innovative companies; products of outstanding quality are made by innovative companies; products which are not 'me-too products' are made by innovative companies; if a product's cost price is not too restrictive, then the company can be more innovative; products which when launched were new for the branch of industry are made by innovative companies; high-tech products are made by innovative companies.
Figure 7.2 shows us that only two of these six indicators have any substantial correlation with the indicators of DFE performance: companies that develop products with unique features, and companies that develop products which were new to the sector when launched, seem to have a relatively high level of DFE performance. It is remarkable to see that companies which develop products with unique features perform well in terms of all five indicators for DFE result.

The fact that two indicators of innovativeness show negative correlations is not surprising; the scales applied here were the reverse of those for all the other indicators of innovativeness.

Innovativeness C

Another type of indicator of innovativeness is the company's own opinion. If a company thinks it is more innovative than its competitors, it will have an innovative attitude and is therefore assumed to yield a relatively high DFE performance. This assumption is however not supported by the empirical data: with respect to this indicator Figure 7.2 shows only a weak and contradicting correlation with the indicators of DFE performance.

Innovativeness D

Somewhat more objective indicators of a company's innovativeness were derived from Cooper (1984) who took the percentage of annual sales and the respective annual profits in a specific year resulting from those products the company had launched over the preceding five years. When this is applied in the study reported here, we see only a weak correlation between these two indicators of innovativeness and a company's DFE performance.

To conclude hypothesis 3.A there would seem to be at least some empirical evidence to support the assumption that the more innovative a company, the higher its DFE performance. However, not all the indicators of innovativeness that were applied support this hypothesis to the same extent. Most correlations turned out to be weak. Indicators of innovativeness which yielded considerable correlations with a company's DFE result and DFE learning are: the extent to which a company experiments, searches actively for new product ideas, invests in R&D, markets products with unique product features, and offers products which are highly innovative in the sense that they were new to that particular industry.
Because of the explorative character of this study, only bivariate statistical techniques were used. Further multivariate analysis is recommended to assess the mutual relation between the indicators of innovativeness as applied in this study, and to relate them to a company's DFE performance.

Hypothesis 3.B Companies with a high level of environmental awareness and activities have a higher DFE performance than companies with less environmental awareness and fewer environmental activities.

The second sub-hypothesis, 3.B, is formulated above. Chapter 4 proposed a range of indicators for measuring a company's environmental awareness. The first indicator of environmental awareness is the presence of an Environmental Management System. Companies that have expressed their environmental awareness in a (partial) EMS are more environmentally aware than companies with no EMS and are assumed to have a relatively high DFE performance level.
Figure 7.3 lists the substantial correlations between this environmental awareness indicator and the indicators of DFE performance. They support our assumption: companies with a (partial) EMS yield a relatively higher DFE performance than companies with no EMS.

	DFE Result					DFE Learning				
	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE result scale	DFE objectives	DFE involvem. extern	DFE awareness	DFE specification	DFE learning scale
Environmental awareness:										
Presence of EMS, v051, η	**0.35** (72)	0.23 (72)	**0.31** (75)	0.21 (74)	**0.35** (71)	**0.43** (54)	0.09 (67)	0.18 (72)	0.08 (48)	**0.29** (37)
Particip. in other IC eco-project, v052, η	0.24 (53)	0.19 (53)	0.05 (55)	0.10 (55)	0.19 (53)	**0.28** (40)	0.23 (51)	0.07 (54)	**0.25** (37)	**0.33** (29)
Subscription to env. covenant, v053, η	0.08 (56)	0.08 (56)	0.22 (58)	0.22 (57)	0.16 (55)	0.19 (41)	0.16 (53)	**0.36** (56)	0.07 (38)	0.20 (28)
Estimated environm. initiatives, v054, r	0.06 (67)	0.01 (67)	-0.01 (70)	-0.04 (69)	0.05 (66)	0.12 (52)	0.05 (62)	0.20 (68)	-0.05 (43)	0.11 (36)

No. of environmental benchmarking,v055, r	-0.13 (66)	-0.03 (66)	-0.02 (68)	-0.01 (67)	-0.09 (65)	-0.03 (50)	-0.02 (62)	-0.01 (65)	-0.03 (44)	-0.29 (34)
Explicit environmental responsible, v056b, η	0.06 (72)	0.06 (72)	0.02 (75)	0.05 (74)	0.02 (71)	0.23 (54)	0.11 (67)	0.29 (72)	0.05 (48)	0.14 (37)

Figure 7.3 *Correlation coefficients (Spearman's r or η) between indicators of a company's environmental awareness and its DFE result and DFE learning*

Having participated in the preceding IC project 'Cleaner Production' was the second indicator of environmental awareness. However, the empirical data hardly supports the assumption that the companies that participated in the IC project 'Cleaner Production' show a higher level of DFE performance. The same applies with regard to the other four indicators of environmental awareness. These were: subscription to an environmental covenant, how the company ranked itself in terms of its own environmental initiatives as opposed to those of its competitor, performance of an environmental benchmark, and the explicit assignment of environmental responsibilities to specific employees. As a whole, the correlations between these environmental awareness indicators and those of DFE performance are generally too weak to support hypothesis 3.B. This might be due to our high expectations concerning the environmental initiatives of the companies studied. For example, we can only expect a few companies to have actually performed an environmental benchmark. It is therefore hardly surprising to see that no better correlations were found.

Correlation between the various indicators of a company's DFE awareness and the indicators of DFE performance is usually weak. The only exception in this respect is if an Environmental Management System is in place. This seems to be a good predictor for a company's DFE performance. The empirical data show that companies with a (partial) EMS yield a relatively higher DFE performance than those without an EMS.

Hypothesis 3.C: Companies with a positive attitude towards DFE will manifest a higher DFE performance than those with a critical attitude.

The final sub-hypothesis of hypothesis 3 is defined above. It links a company's DFE attitude with the DFE performance resulting from the IC EcoDesign project. A company's DFE attitude is measured by means of four separate indicators. The results of the correlation analyses are given in Figure 7.4.

	DFE Result					**DFE Learning**				
	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE result scale	DFE objec-tives	DFE involvem. extern	DFE aware-ness	DFE specifi-cation	DFE learning scale
DFE attitude A:										
DFE experience before scan, v063, r	0.14 (72)	0.08 (72)	0.12 (75)	0.07 (74)	0.06 (71)	0.21 (54)	0.10 (67)	0.00 (72)	0.29 (48)	0.20 (37)
DFE attitude B:										
DFE attitude of corp. management, v065, r	0.09 (71)	0.08 (71)	0.17 (74)	0.31 (73)	0.14 (70)	0.33 (53)	0.31 (66)	0.22 (71)	0.34 (48)	0.41 (37)
DFE attitude of dept. product devt., v066, r	0.14 (70)	0.20 (70)	0.26 (73)	0.37 (72)	0.24 (69)	0.39 (53)	0.38 (65)	0.15 (70)	0.33 (48)	0.46 (37)
DFE attitude of dept. market./sales, v067, r	-0.02 (70)	0.04 (70)	0.15 (73)	0.33 (72)	0.13 (69)	0.31 (53)	0.33 (65)	0.30 (70)	0.37 (48)	0.39 (37)
DFE attitude of dept. environment, v068, r	-0.08 (69)	-0.10 (69)	0.10 (72)	0.18 (71)	0.00 (68)	0.16 (52)	0.18 (64)	0.05 (69)	0.10 (47)	0.12 (36)
DFE attitude of dept. quality, v069, r	-0.18 (70)	-0.14 (70)	-0.05 (73)	0.19 (72)	-0.07 (72)	0.06 (53)	0.02 (65)	0.05 (70)	0.09 (48)	0.09 (37)
DFE attitude of dept. purchasing, v070, r	-0.01 (71)	-0.03 (71)	0.04 (74)	0.04 (73)	-0.02 (70)	0.23 (53)	-0.02 (66)	0.19 (71)	0.12 (48)	0.17 (37)
DFE attitude of dept. production, v071, r	0.07 (71)	-0.02 (71)	-0.01 (74)	0.18 (73)	0.05 (70)	0.13 (54)	0.06 (66)	0.01 (71)	0.09 (48)	0.03 (37)

DFE attitude C:										
Explicit goal to improve product, v075, r	0.05 (70)	0.06 (70)	0.02 (72)	0.00 (71)	-0.02 (69)	0.36 (51)	0.23 (65)	0.28 (70)	0.40 (46)	0.45 (36)
DFE attitude D:										
DFE is element prod. innovation, v078, r	-0.09 (72)	-0.06 (72)	-0.01 (74)	0.16 (73)	-0.03 (71)	0.28 (53)	0.32 (67)	0.31 (72)	0.27 (47)	0.41 (37)
DFE is element of prod. quality, v079, r	-0.08 (70)	-0.17 (70)	-0.07 (72)	0.09 (71)	-0.04 (69)	0.22 (51)	0.18 (65)	0.07 (70)	0.03 (46)	0.20 (36)

Figure 7.4 *Correlation coefficients (Spearman's r or η) between four sets of indicators of a company's DFE attitude and its DFE result and DFE learning*

DFE attitude A

The first indicator of a company's DFE attitude was the company's previous experience with DFE before the Environmental Innovation Scan was performed. The assumption was that companies which have already applied DFE will have a positive DFE attitude, and will consequently yield a high DFE performance.
Figure 7.4 shows that the correlation between this DFE attitude indicator and the indicators of DFE performance are generally too weak to be indicative of a distinct relationship. One reason for this could be that companies which already applied EcoDesign principles to their products, only made a smaller step forward than those for which EcoDesign was a completely new topic.

DFE attitude B

Another indicator of DFE attitude was defined as the attitude various company departments had towards DFE: if the management and the departments of product development, marketing/sales, environmental affairs, quality assurance, purchasing and production have an active DFE attitude, the company's DFE attitude is said to be positive. With regard to the first three of this set of DFE attitude indicators, Figure 7.4 shows a substantial correlation with DFE performance. The DFE performance is relatively higher if the management, the product development department, or the sales/marketing department, feel committed towards DFE. The correlations are much weaker with regard to the other four indicators of DFE attitude: the DFE commitment of the environmental, quality, purchasing and production departments.

DFE attitude C

The third indicator of a company's DFE attitude is referred to as its 'DFE ambition': if the company had the specific ambition to improve the product's eco-efficiency it has a positive DFE attitude. Figure 7.4 leads to the conclusion that this positive DFE attitude relates to a large extent to the DFE learning displayed by a company; the correlation with the indicators of DFE result are less convincing. This could imply that the study included companies in which there is a strong commitment towards DFE, but which only manage to apply DFE to their products in the longer term.

DFE attitude D

The last set of indicators of a company's DFE attitude is DFE perception: if a company perceives DFE as an important aspect of product innovation, or if it regards a high level of eco-efficiency as an element of product quality, then it has a positive DFE attitude. Figure 7.4 reveals only a limited number of substantial correlations with regard to the relation between these DFE attitude indicators and the indicators of DFE performance. Convincing correlations are found only between a company's DFE learning and the extent to which it perceives DFE as an important aspect of product innovation.

Reflecting on hypothesis 3.C we can conclude that the DFE attitude of the company's management, its product development department and its marketing/sales department are indeed good predictors of a high level of DFE performance in terms of both DFE result and DFE learning. If these departments have a positive attitude towards DFE we can expect relatively high scores for the company's DFE result and DFE learning. The correlations between the other sets of indicators reflecting a company's DFE attitude and its DFE performance indicators are not strong enough to further support this hypothesis.

Additional company characteristics

Because the research setting also offered the opportunity to measure some organizational aspects, additional attention was given to the question: what is the impact on the DFE performance of a selection of organizational company characteristics. The first variable is ***number of employees***. One often-heard assumption is that a company's DFE performance depends on its size. Chapter 4 made reference to some studies which concluded that: the larger the company, the more significant its efforts in environmental management (Van Someren et al., 1993; Lehmann, 1993). However, other studies deny this or conclude exactly the opposite (Carter, 1995; Potter, 1992; Smith et al., 1996). As an example Smith et al. (1996), who studied sixteen companies which introduced significant environmental improvements to the design of their products, concluded that the small companies studied (defined as having less than 100 employees) tended to be more pro-active, developing innovative green products for niche markets with relatively small investments. Larger companies, they found, tended to be more reactive and to adapt existing products or innovations to satisfy volume markets.
The empirical data of the present study, listed in Figure 7.5 below, do not convincingly support any of these assumptions. Most of these variables show a weak correlation in the negative sense; this negative correlation stands out particularly with respect to DFE learning. It indicates that smaller companies have achieved a relatively high level of DFE learning. This could be due to the fact that these companies learned relatively more from the project than larger companies which were more likely to be familiar with the subject of DFE.

Hence, the empirical studies on the subject report contradicting conclusions regarding the influence of company size. In order to understand this, a more unmistakable distinction should be made between the type of environmental initiatives that were the subject of the studies mentioned. With regard to environmental initiatives in the sense of implementing an EMS or cleaning technologies, it seems only obvious for larger companies to be more active than smaller companies. Such initiatives are taken because companies must comply with standards and regulations. However, if we look at the environmental initiatives in the sense of design for environment the situation becomes different. There are hardly any standards or regulation that exist on this subject matter. Consequently, it usually depends on a company's cultural characteristics whether or not it applies DFE to its products. Generally speaking it is difficult to say that larger companies are more innovative than smaller ones. It is therefore not surprising to see that the empirical findings of this study do not show that larger companies are more eco-innovative than their smaller counterparts. Why then do Smith et al. find that the small companies they studied were more 'pro-active' than the larger companies? This is most probably because of the specific companies they selected for their study. The smaller companies they had selected had won, or had been commended in, the 'Green Product' category of an industrial environmental award. The larger companies were participants in the EU Ecolabeling programme or had been recommended by environmental organizations. In short, they were all already relatively 'pro-active'. The companies that participated in the study reported in this thesis, however, had very limited DFE experience, or none at all, and are a far cry from what could be termed as 'pro-active'. Therefore, further comparison is not justified.

	DFE Result					**DFE Learning**				
	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE result scale	DFE objec-tives	DFE involvem. extern	DFE aware-ness	DFE specifi-cation	DFE learning scale
Additional variables:										
Number of employees, v019, r	0.10 (63)	-0.02 (63)	-0.02 (66)	-0.10 (65)	-0.04 (62)	-0.22 (47)	-0.09 (58)	-0.24 (63)	**-0.28 (42)**	**-0.39 (33)**
Industrial sector, v021, η	**0.71 (71)**	**0.75 (71)**	**0.47 (74)**	**0.52 (73)**	**0.66 (70)**	**0.34 (53)**	**0.52 (66)**	**0.51 (71)**	**0.51 (47)**	**0.38 (36)**
No. of in-house prod. developers, v020, r	0.23 (58)	**0.25 (58)**	0.19 (61)	**0.32 (60)**	**0.34 (57)**	-0.05 (43)	0.14 (55)	0.23 (59)	-0.04 (41)	0.15 (31)
Company is 'self specifying', v023, η	0.01 (64)	0.06 (64)	0.06 (66)	0.12 (65)	0.11 (63)	0.07 (47)	0.03 (59)	0.16 (63)	0.02 (43)	0.05 (32)
Product is 'end product', v024, η	0.07 (69)	0.06 (69)	0.06 (72)	0.04 (71)	0.02 (68)	0.01 (51)	0.03 (64)	0.01 (69)	0.03 (46)	0.05 (35)

Core activities of company, v026, η	0.24 (72)	0.26 (72)	0.32 (75)	0.29 (74)	0.33 (71)	0.38 (54)	0.38 (67)	0.22 (72)	0.18 (48)	0.29 (37)
Written procedures for R&D, v022, η	0.32 (60)	0.22 (60)	0.44 (62)	0.24 (61)	0.37 (59)	0.18 (48)	0.07 (56)	0.10 (60)	0.09 (42)	0.09 (34)
Product development tradition, v043, r	0.05 (66)	0.10 (66)	0.16 (68)	-0.01 (67)	0.13 (65)	0.33 (49)	0.10 (61)	0.02 (65)	0.32 (46)	0.36 (35)
Presence of Quality System, v050, η	0.13 (71)	0.07 (71)	0.24 (74)	0.11 (73)	0.02 (70)	0.23 (53)	0.18 (66)	0.16 (71)	0.35 (47)	0.36 (36)

Figure 7.5 *Correlation coefficients (Spearman's r or η) between a set of additional company characteristics and a company's DFE result and DFE learning*

The relationship between the company's **branch of industry** and its DFE performance is more evident; the correlation between the branch of industry and the DFE performance indicators are quite substantial with regard to the indicators of DFE learning and sometimes even equally as strong with regard to the DFE result indicators. In some branches of industry the DFE performance is obviously higher than in others. One of the reasons for this is that the different branches of industry vary to a quite large extent in terms of the importance of new product development. Further analysis shows that the branches of industry in which the highest results are achieved are the electronics industry (where 3 out of 4 companies scored very high) and the machine industry (5 out of 12 companies had high scores). Other branches of industry which also have considerably high scores are the metal products industry (high scores for 4 out of 19 companies), the wood and furniture industry (3 out of 11 companies scored high) and the textile industry (2 out of 4 companies scored high).

The presence of an **in-house product development** department correlates substantially with the indicators of DFE result; however, the correlation between this variable and the indicators of DFE learning are weak. Another organizational characteristic studied was the **'freedom of specification'**, or the extent to which the company can specify its products 'autonomously'. The assumption was that the more autonomy a company has to specify its products, the higher its level of DFE performance will be. The correlations listed in Figure 7.5 are too weak however to support this assumption. The same applies in respect of the variable 'product is end product'. There seems to be only a weak relation between these variables and a company's DFE performance.
In contrast, the **company's core activities** do seem to have a strong bearing on its DFE performance. It was not surprising to see that the correlations shown in Figure 7.5 and further analysis showed that those companies that regard product development as one of their core activities displayed a higher DFE performance than those focusing on other activities.
The extent to which **written procedures** are used in product development correlates significantly with the indicators for DFE result. Systematic product development seems to enhance the implementation of EcoDesign. However, the correlations are weaker with respect to the indicators of DFE learning. The assumption that a company with a well structured development process will show a relatively high level of DFE performance is only partly supported by the empirical data. Finally, Figure 7.5 shows that a company's product **development tradition** (the number of years it has been developing products) has a substantial correlation to the company's DFE learning only. The longer this tradition, the more the company's DFE learning. This is also the case with regard to the presence of a **quality system**.

The conclusion therefore is that certain organizational company characteristics seem to bear a relation with a company's DFE performance. The empirical data show that the branch of industry to which the company belongs, as well as its DFE performance, are considerably correlated, implying that DFE performance depends on the branch of industry to which a company belongs. Another good predictor of a high DFE performance level is its core activity; if a company regards product development as one of its core activities, its DFE performance is evidently relatively high in terms of both DFE result and DFE learning. The often-heard statement that a company's DFE performance depends on company size is contradicted by the empirical findings of this study.

.3.3 Product characteristics; reflecting on hypothesis 4

We may assume that the character of a specific product has a strong influence on a company's DFE performance. This assumption was worked out in detail into the set of hypotheses 4.A and 4.B in Chapter 4. In this section both hypotheses will be reflected on, using the empirical findings. The relation between product characteristics (explanatory variables), and the indicators of DFE performance (dependent variables), were assessed on the basis of correlation analyses.

Hypothesis 4.A Products subjected to external pressure with regard to their eco-efficiency will prompt a higher DFE performance than those which are not.

Various empirical studies emphasize that external pressure is a prerequisite to motivate industry to incorporate environmental concern in their activities. We therefore assumed that companies that experience strong external pressure towards DFE will yield better results than those which do not. This led to hypothesis 4.A. The extent to which the product is subject to external pressure was measured by five different sets of indicative variables. All correlation coefficients calculated between these variables and a company's DFE result and DFE learning are listed in Figure 7.6.

	DFE Result					DFE Learning				
	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE result scale	DFE objec-tives	DFE involvem. extern	DFE aware-ness	DFE specifi-cation	DFE learning scale
External pressure A:										
Product selected due to legislat. v014s3, η	0.03 (74)	0.07 (74)	0.04 (77)	0.03 (74)	0.05 (71)	0.23 (54)	0.16 (67)	0.14 (72)	0.16 (48)	**0.25 (37)**
Legislation makes DFE necess., v059, r	0.16 (72)	0.17 (72)	0.13 (75)	0.02 (74)	0.14 (71)	0.20 (54)	**0.25 (67)**	0.15 (72)	**0.25 (48)**	**0.33 (37)**
External pressure B:										
Particip. due to legislation, v077, r	0.07 (71)	0.08 (71)	0.11 (73)	0.13 (72)	0.11 (70)	**0.29 (52)**	0.12 (66)	0.21 (71)	**0.25 (47)**	**0.31 (37)**
Particip. due to cust. demands, v082, r	0.06 (71)	0.02 (71)	-0.04 (73)	-0.09 (72)	-0.04 (70)	**0.26 (52)**	**0.31 (66)**	0.13 (71)	**0.31 (47)**	**0.29 (37)**
Particip. to prevent negat. image, v083, r	-0.17 (71)	-0.17 (71)	-0.23 (73)	-0.09 (72)	-0.17 (70)	0.18 (52)	0.16 (66)	0.04 (71)	0.24 (47)	**0.33 (37)**
Particip. due to activ. competitors, v084, r	0.15 (71)	0.07 (71)	0.05 (73)	-0.02 (72)	0.10 (70)	**0.46 (52)**	0.14 (66)	0.11 (71)	**0.28 (47)**	**0.42 (37)**
External pressure C:										
Non-toxic materials declaration, v094, r	0.19 (61)	**0.25 (61)**	**0.27 (63)**	0.02 (62)	0.20 (60)	0.04 (46)	0.12 (57)	0.07 (60)	0.07 (41)	0.01 (31)
Take-back declaration, v095, η	0.08 (66)	0.02 (66)	0.04 (68)	0.17 (67)	0.00 (65)	0.10 (51)	**0.33 (61)**	**0.26 (65)**	0.06 (45)	0.01 (35)
Branch subscribed covenant, v096, η	0.16 (53)	0.11 (53)	0.18 (53)	0.10 (54)	0.20 (52)	0.17 (40)	0.17 (50)	0.18 (54)	0.05 (37)	0.01 (29)
Branch was target of env. action, v098, η	0.08 (52)	0.07 (52)	0.11 (54)	0.01 (53)	0.11 (51)	0.07 (38)	0.21 (47)	0.19 (52)	0.24 (36)	0.06 (27)
External pressure D:										
DFE attitude of indus-trial sector, v099, r	-0.22 (69)	**-0.37 (69)**	-0.19 (72)	-0.13 (72)	**-0.31 (69)**	**0.25 (51)**	0.04 (66)	-0.22 (70)	0.05 (47)	0.06 (36)
DFE attitude of Dutch government, v100, r	0.06 (71)	-0.03 (71)	0.08 (74)	-0.03 (73)	0.02 (70)	-0.08 (53)	-0.11 (67)	0.08 (71)	0.00 (48)	-0.19 (37)
DFE attitude of customers, v101, r	0.04 (71)	0.06 (71)	0.04 (74)	-0.06 (73)	0.00 (70)	**0.40 (53)**	**0.30 (67)**	0.02 (71)	**0.27 (48)**	**0.28 (37)**
DFE attitude of end users product, v102, r	-0.05 (71)	0.10 (71)	-0.04 (74)	0.17 (73)	0.02 (70)	**0.31 (53)**	**0.30 (67)**	0.13 (71)	**0.33 (48)**	**0.36 (37)**
DFE attitude of retail/dealers, v103, r	-0.06 (71)	-0.09 (71)	0.05 (74)	0.01 (73)	-0.04 (70)	0.23 (53)	0.22 (67)	-0.09 (71)	**0.28 (48)**	0.15 (37)
DFE attitude of suppliers, v104, r	0.22 (71)	**0.31 (71)**	0.21 (74)	0.10 (73)	**0.30 (70)**	**0.32 (53)**	0.19 (67)	0.03 (71)	0.24 (48)	0.10 (37)
DFE attitude of competitors, v105, r	0.15 (70)	0.11 (70)	0.07 (73)	-0.10 (72)	0.02 (69)	0.22 (52)	0.01 (66)	-0.09 (70)	0.13 (48)	0.01 (37)

External pressure E:										
Stimulated by branch of industry, v106, r	0.07 (67)	0.10 (67)	-0.11 (70)	-0.08 (69)	0.00 (66)	0.21 (49)	0.22 (64)	0.07 (68)	0.08 (46)	0.31 (35)
Stimulated by Dutch government, v107, r	-0.09 (70)	-0.06 (70)	0.00 (73)	-0.06 (72)	-0.09 (69)	0.19 (52)	0.17 (67)	0.04 (71)	0.18 (48)	0.21 (37)
Stimulated by customers, v108, r	-0.02 (70)	0.07 (70)	0.03 (72)	-0.04 (71)	0.01 (69)	0.47 (52)	0.55 (67)	0.12 (70)	0.49 (48)	0.56 (37)
Stimulated by end users product, v109, r	-0.09 (70)	-0.12 (70)	-0.10 (72)	0.05 (71)	-0.02 (69)	0.26 (52)	0.48 (67)	0.09 (70)	0.42 (48)	0.43 (37)
Stimulated by retailers, v110, r	0.13 (70)	0.15 (70)	0.06 (72)	0.10 (71)	0.15 (69)	0.35 (52)	0.47 (67)	0.28 (70)	0.49 (48)	0.56 (37)
Stimulated by cons. organization, 111, r	0.08 (70)	0.16 (70)	0.08 (72)	0.11 (71)	0.18 (69)	0.24 (52)	0.30 (67)	0.28 (70)	0.32 (48)	0.37 (37)
Stimulated by env. action groups, v112, r	-0.04 (70)	0.05 (70)	0.07 (72)	0.07 (71)	0.06 (69)	0.11 (52)	0.33 (67)	0.17 (70)	0.17 (48)	0.20 (37)
Stimulated by suppliers, v113, r	-0.04 (70)	0.06 (70)	0.12 (72)	0.05 (71)	0.09 (69)	0.12 (52)	0.36 (67)	0.15 (70)	0.26 (48)	0.31 (37)
Stimulated by competitors, v114, r	-0.01 (70)	0.05 (70)	-0.03 (72)	-0.11 (71)	-0.06 (69)	0.23 (52)	0.33 (67)	-0.03 (70)	0.34 (48)	0.31 (37)

Figure 7.6 *Correlation coefficients (Spearman's r or η) between five sets of variables operationalizing external pressure to use DFE on the product and a company's DFE result and DFE learning*

External pressure A

The first indicator was the 'reason for selecting the product'. If a company had selected the product because of current or pending environmental legislation, then the product was subject to external DFE pressure and the company was expected to manifest a relatively high level of DFE performance. The empirical findings, listed in Figure 7.6, show that there are some correlations, but they are too weak to support this expectation (a 'weak' correlation coefficient is lower than 0,25).
Another indicator was thought to be 'the the necessity of DFE', as perceived by a company. If environmental legislation makes DFE inevitable for a company, the product is subject to external DFE pressure. Figure 7.6 shows that here too are some correlations to be found, but they are generally only weak. However, the correlations are quite significant with regard to the DFE learning indicators (a 'considerable' correlation coefficient is between 0.25 and 0.65).

External pressure B

The same applies with regard to the following set of four indicators of external pressure, related to the reasons the companies had given for participating in the IC EcoDesign project. A product is subject to external DFE pressure if a company had participated in the IC EcoDesign project because it wished to be informed about environmental legislation, because its customers were demanding eco-efficient products, because the product risked a negative environmental image, or because the company wanted to overtake a competitor with regard to the eco-efficiency of their products. The calculated correlations are weak with regard to the indicators of DFE result, but become more significant for the DFE learning indicators. This effect, which occurs regularly with respect to product characteristics, is quite remarkable. An explanation for this could be that while a company is willing and ready to apply DFE (evident from the DFE learning indicators), it has not yet managed to realize the DFE intentions in actual product modifications (measured on the basis of the DFE result indicators).

External pressure C

Two other indicators of external DFE pressure are 'the environmental demands of customers' as perceived by the companies. If a company had signed a non-toxic materials declaration in connection with a product, or if a guarantee has been undertaken to take back products after their functional life has expired, then such products are subject to external DFE pressure. The empirical findings lead to some considerable correlations, as shown in Figure 7.6, yet they are not convincing enough to support the assumption that the environmental demands of their customers had led to a higher level of DFE performance.

Only weak correlations were found with respect to the following two indicators of external pressure. The first is the existence of an environmental covenant at branch of industry level. If the branch of industry to which the company belongs had agreed to enter into an environmental covenant with the government, it is assumed that the product is subject to external DFE pressure and a higher DFE performance is expected. The second relates to the activities of environmental action groups. If the company's branch of industry has ever been the target of environmental action group activity, the product is subject to environmental pressure. Neither of these indicators seem to be good predictors of a high DFE performance.

External pressure D

The 'attitude of external actors towards DFE', as experienced by a company, was believed to influence that company's DFE performance. If the attitude towards DFE of the company's branch of industry, government, direct customers, end users, retailers/dealers, suppliers, or competitors is one of involvement, the product is subject to external DFE pressure and prompts DFE initiatives. Not all of the correlations between these indicators of external pressure and the DFE performance indicators are convincing. The first exception is that when direct customers or product end users have an active DFE attitude, the relevant companies seem to have good results in terms of DFE learning. The fact that correlation between these external pressure indicators and the indicators of DFE result is not considerable, could mean that whereas the companies had planned to take DFE initiatives, they had not yet managed to actually implement them. The second exception relates to the DFE attitude of suppliers. If a company's supplier has an active DFE attitude it would seem to enhance both the company's DFE result and its DFE learning. A remarkable result was found with regard to the attitude in the different branches of industry: the more active the branch of industry, the lower the company's DFE result. This could imply that companies with a low DFE performance dislike the active DFE attitude in their branch of industry and exaggerate the amount of pressure it exerts on implementing DFE. They could feel 'forced' to take steps towards DFE. Further study is required to understand this effect.

External pressure E

The companies were also asked to indicate how stimulated they were by the external actors mentioned above. If a company felt that it was stimulated to implement DFE by the company's branch of industry, by governmental regulations, direct customers, end users, retailers/dealers, suppliers, competitors, consumer organizations or environmental action groups, then the product is subject to external DFE pressure. The expectation was that the more intense this external stimulation, the higher the DFE performance would be. The correlations listed in Figure 7.6 show a similar picture as sketched just above. The correlation coefficients are quite considerable in respect of DFE learning indicators, but weak regarding the indicators of DFE result. Again we see that DFE stimulation on the part of direct customers and end users (and also by retailers/dealers) leads to the highest correlation coefficients compared to the other external actors.

As a whole, hypothesis 4.A is supported by the empirical findings of this study. Several sets of indicators were applied to measure the external pressure towards DFE in relation to the products concerned. It is remarkable to see that many of these indicators of external pressure are considerably correlated with the indicators of DFE learning, even though they are usually only weakly correlated with the DFE result indicators. Only if suppliers are active in DFE does the DFE result seem better. A possible explanation for this effect could be that a company which experiences strong stimuli towards DFE from external actors is willing to start DFE initiatives in the near future but has not as yet managed to convert these intentions into concrete deeds. Quite substantial correlations are found mainly with the DFE pressure indicators which represent government legislation, environmental demands from customers and end users, and the environmental initiatives of competitors. Specially high correlations are found with regard to DFE attitude and stimuli from customers and end users. This indicates that of all the actors that might influence a company to take steps towards DFE, the company's customers and the end users of their products would seem to be the most influential.

Hypothesis 4.B Products for which DFE offers commercial opportunities will lead to a higher level of DFE performance than products for which DFE is perceived as commercially neutral or negative.

This second sub-hypothesis, 4.B, with regard to product characteristics is based on the assumption that a company's DFE performance depends on the extent to which DFE results in synergy with the existing business values, or commercial opportunities.
Three sets of indicators were constructed to measure the commercial opportunities DFE offers to the products in question. The correlation coefficients reflecting the relation between the three sets of indicators and the company's DFE result and DFE learning are listed in Figure 7.7 below.

	DFE Result					DFE Learning				
	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE result scale	DFE objec-tives	DFE involvem. extern	DFE aware-ness	DFE specifi-cation	DFE learning scale
Commercial opportunities A:										
DFE yields commer-cial benefit, v057, r	0.33 (72)	0.27 (72)	0.24 (75)	0.19 (74)	0.29 (71)	0.14 (54)	0.20 (67)	0.27 (72)	0.14 (48)	0.22 (37)
DFE may be sales argument, v058, r	0.06 (72)	0.06 (72)	0.04 (75)	0.04 (74)	0.07 (71)	0.49 (54)	0.41 (67)	0.06 (72)	0.44 (48)	0.51 (37)
Participation for 2nd. opinion v085, r	-0.12 (71)	-0.07 (71)	-0.09 (73)	-0.11 (72)	-0.10 (70)	0.38 (52)	0.33 (66)	0.15 (71)	0.50 (47)	0.50 (37)
DFE costs will be recovered, v061, r	0.16 (71)	0.20 (71)	0.27 (74)	0.31 (73)	0.29 (70)	0.30 (53)	0.31 (66)	0.49 (71)	0.38 (47)	0.51 (36)
DFE increases efficiency, v080, r	0.12 (72)	0.09 (72)	0.26 (74)	0.22 (73)	0.18 (71)	0.11 (53)	0.19 (67)	0.25 (72)	0.31 (47)	(0.40 (37)
Commercial opportunities B:										
Influence on material costs, v173, r	0.18 (60)	0.04 (60)	0.26 (61)	0.27 (60)	0.20 (59)	-0.12 (47)	-0.25 (58)	-0.12 (59)	-0.21 (43)	-0.16 (34)
Influence on disposal costs, v174, r	0.18 (52)	-0.01 (52)	0.20 (53)	0.31 (52)	0.14 (51)	-0.04 (41)	-0.14 (50)	0.04 (51)	-0.14 (37)	-0.04 (30)
Influence on costs of production, v175, r	0.23 (61)	0.10 (61)	0.35 (62)	0.35 (61)	0.28 (60)	-0.07 (47)	-0.24 (59)	0.01 (60)	-0.24 (42)	-0.11 (33)
Influence on costs of packaging, v176, r	-0.07 (53)	-0.30 (53)	-0.02 (54)	-0.02 (53)	-0.10 (52)	0.01 (40)	-0.29 (51)	-0.11 (52)	-0.21 (38)	-0.11 (29)
Influence on transport costs, v177, r	0.22 (58)	0.21 (58)	0.40 (59)	0.37 (58)	0.38 (57)	0.11 (44)	-0.01 (56)	-0.03 (57)	-0.09 (41)	0.11 (32)
Influence on costs of take-back, v178, r	-0.03 (36)	-0.09 (36)	0.04 (37)	0.12 (37)	0.04 (36)	-0.26 (32)	-0.39 (36)	-0.08 (35)	-0.20 (29)	-0.49 (23)
Influence on R&D costs, v179, r	0.03 (55)	-0.13 (55)	0.02 (56)	0.20 (55)	0.02 (54)	-0.18 (47)	-0.20 (53)	-0.15 (54)	-0.21 (42)	-0.31 (34)
Commercial opportunities C:										
Increasing market shares, v182, r	-0.05 (66)	0.00 (66)	0.16 (67)	0.22 (66)	0.11 (65)	0.30 (51)	0.28 (63)	0.12 (65)	0.38 (46)	0.43 (37)
Entering new markets, v183, r	-0.03 (63)	0.07 (63)	0.35 (64)	0.20 (63)	0.21 (62)	0.43 (51)	0.37 (60)	0.04 (62)	0.48 (45)	0.52 (37)
Estimated total profit of EcoDesignv184, r	0.42 (50)	0.47 (50)	0.54 (51)	0.45 (51)	0.54 (50)	0.52 (40)	0.34 (49)	0.30 (51)	0.63 (36)	0.74 (31)

Figure 7.7 *Correlation coefficients (Spearman's r or η) between three sets of indicators for 'commercial opportunities' of DFE for the specific product and the company's DFE result and DFE learning*

Commercial opportunities A

The first indicator was defined as the extent to which the company regarded DFE as an opportunity for financial gain. As expected, Figure 7.7 shows that the correlations found between this commercial value indicator and the indicators of DFE performance are considerable.
Some considerable correlations were also calculated with regard to two other commercial value indicators as well, but only in connection with DFE learning. Both indicators refer to the extent to which the company can use DFE as a marketing instrument/sales argument. This could imply that companies regarding DFE as a marketing instrument, are both ready and willing to take DFE initiatives, but have not yet managed to realize product improvements.
The extent to which DFE is seen as an initial investment, the costs of which will be recovered over a period of time, is another indicator of the commercial value of DFE for the products involved. Figure

7.7 makes it obvious that this indicator is considerably correlated with most indicators of DFE performance. The extent to which DFE is seen as an investment that will *not* be recovered in due course is another indicator. In line with our expectations, the correlations between this indicator and the DFE performance indicators are also quite considerable, but this time in a negative sense. These outcomes make the commercial value indicator in question even more convincing.
The companies were also asked how far they saw DFE as a means of increasing their operational efficiency. Again we see a considerable correlation between this indicator and various DFE performance indicators.

Commercial opportunities B

Another set of seven indicators measures the extent to which the companies feel that various costs are influenced by DFE: purchasing costs of materials and components, waste removal costs, production costs (including costs for tool adjustment, testing, internal logistics, guarantee/repair), packaging costs, transport costs, future take-back costs and R&D costs. Only two of these indicators have a significant correlation with the indicators of DFE performance; this correlation was however limited to the DFE result indicators. A company's DFE result (realized product, process or packaging improvements) only seems to be improved if a company states that the production or transport costs for the product in question have been reduced thanks to DFE. Future take-back costs play a remarkable role given that this indicator is negatively correlated with DFE learning indicators. Companies that foresee high costs in consequence of their obligation to take their products back seem to be less willing to take DFE initiatives. They may tend to exaggerate the expected take-back costs because of internal resistance to do so. Further study is required to study this effect.

Commercial opportunities C

Furthermore, two commercial value indicators can be derived from the degree to which an increase of sales is expected thanks to an increase in market share or the opportunity to launch products on new markets as a result of DFE. Both indicators show a considerable correlation with respect to DFE learning; correlation with the indicators of DFE result is somewhat less convincing.
The total financial gains from the application of DFE expected by the company is related quite convincingly to its DFE performance. Not surprisingly, we can conclude that if a company expects a high total profit from introducing DFE, its DFE performance will be high.

With regard to the indicators of the commercial value of DFE for the products concerned, the empirical findings reveal some convincing predictors for DFE performance. Hypothesis 4.B is therefore supported by the empirical findings. t is not surprising to see that convincing predictors would seem to be the extent to which a company regards DFE as a commercial opportunity, an initial investment that is recovered in due course, an opportunity to increase efficiency, a means to reduce production or transport costs, or a means to increase market shares or penetrate new markets. A very convincing correlation is seen between the company's DFE performance and its estimation of the total commercial profit of DFE in two years' time.

Additional product characteristics

In addition to the hypotheses set out above, the relationship between a company's DFE performance and an additional set of product characteristics was also investigated. This resulted in some interesting, unexpected conclusions described below. Figure 7.8 lists the correlation coefficients that were found.

	DFE Result					**DFE Learning**				
	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE result scale	DFE objec-tives	DFE involvem. extern	DFE aware-ness	DFE specifi-cation	DFE learning scale
Additional variables:										
Geographical market of product, v002, η	0,32 (71)	0,26 (71)	0,27 (74)	0,20 (73)	0,32 (70)	0,34 (53)	0,26 (66)	0,12 (71)	0,39 (48)	0,32 (37)
Year the product was launched, v005, r	0,64 (64)	0,60 (64)	0,59 (67)	0,60 (66)	0,69 (63)	0,65 (48)	0,63 (60)	0,62 (64)	0,69 (43)	0,71 (33)

Number of completed redesigns, v006, r	**0,31** (67)	0,24 (67)	**0,31** (69)	**0,25** (68)	**0,26** (66)	**0,29** (51)	**0,42** (63)	**0,29** (66)	**0,47** (45)	**0,38** (35)
Stage in product life cycle, v011, η	0,24 (67)	0,13 (67)	0,07 (70)	0,08 (69)	0,15 (66)	**0,48** (49)	0,21 (62)	0,08 (67)	**0,51** (43)	**0,39** (32)
Lifetime of product, v012, r	**-0,30** (65)	-0,24 (65)	**-0,25** (67)	-0,09 (66)	**-0,28** (64)	-0,11 (49)	-0,08 (63)	-0,07 (64)	-0,09 (46)	-0,05 (35)
Type of market, v013, η	0,17 (70)	0,22 (70)	0,20 (73)	**0,32** (72)	0,24 (69)	0,22 (53)	0,13 (65)	**0,34** (70)	**0,33** (48)	0,22 (37)

Figure 7.8 *Correlation coefficients (Spearman's r or η) between additional product characteristics and a company's DFE result and DFE learning*

First of all the influence of the product's ***geographical market*** on the company's DFE performance was studied. Products sold in both the Netherlands and Germany are subject to a great deal of environmental legislation and will therefore bring about a higher DFE performance than those sold in other countries. Hutchinson and Chaston (1994) concluded that companies exporting to the UK found environmental issues to be significantly more important to their business practices than non-exporters. Figure 7.8 shows that this product characteristic has indeed a considerable correlation with almost all indicators of DFE performance. The results of further analysis support the conclusions of Hutchinson and Chaston: the more widely a product is exported, the higher the DFE performance related to that product seems to be.

Another product characteristic that seems to have a substantial connection with a company's DFE performance is the ***product's age***. The expectation was that companies would be less inclined to apply DFE to products they had recently launched than to products of older age since companies would be hesitant to invest in product development immediately after a products had been launched. Surprisingly, further analysis of the empirical findings showed the opposite to be true. The twenty products launched between 1940 and 1989 each produced a relatively low DFE performance in comparison with products launched more recently.
Also the 'frequency of redesigning' (the number of times a product was redesigned) seems to have a considerable impact on a company's DFE performance. Given that if a product is frequently redesigned DFE improvement options can be realized relatively quickly, it was assumed that products which lend themselves to frequent redesign would produce a higher level of DFE performance than those which have not been subjected to redesign. Here too do we see that the empirical findings show the opposite: the fewer the number of product redesigns accomplished, the higher the product-related DFE performance. The reason for this is probably: the fewer redesigns, the less product optimization. This leaves room for additional product modification.
Furthermore, DFE performance also seems to depend slightly on the stage of the product's ***commercial life cycle***. This does not refer to the product's newness for a specific company, but to the newness of the *type* of product for the industrial sector as a whole. Conform our expectation, the DFE performance was in general somewhat higher for products in their growth stage than for products in the other three stages of their life cycle distinguished (infancy, growth, maturation, decline).
The relation found between a company's DFE performance and a product's ***functional lifetime*** was as expected The expectation was that if a product only has a short functional life (e.g. packaging) the product will be DFE sensitive because of the waste the product causes, and will therefore result in a higher DFE performance.
The last product characteristic studied was ***market type***. The expectation was that products intended for the industrial (business to business) or governmental market trigger a higher DFE performance than products for the consumer market. Figure 7.8 shows some considerable correlations between this product characteristic and the indicators of DFE performance. Further analysis shows that products intended for the industrial market certainly do result in higher DFE performance than those intended for consumer markets. This could be explained by the fact that companies take the environmental demands of industrial and governmental clients more seriously than those of consumers. Furthermore, the environmental demands of consumers, if there any such demands, are often vague.

Exploring the relation between an additional set of product characteristics and the DFE performance of the company involved led to some quite surprising findings. The DFE performance was generally the highest if the

product was exported world-wide, if the product had recently been launched on the market, if the product had not yet been subjected to redesign or had been redesigned only once, if the product was still in the growth stage of its commercial life cycle, if the product had a short functional life time and if the product was intended for the industrial market.

7.3.4 Respondent characteristics; reflecting on hypothesis 5

Chapter 4 formulated the expectation that if the owner-manager of a company participating in the IC EcoDesign project feels a strong commitment towards the environment, this will contribute towards the resulting DFE performance in terms of DFE result and DFE learning. This expectation was elaborated into hypotheses 5.A and 5.B, and will be reflected on in the following.

Hypothesis 5.A A high personal environmental commitment of the company representative contributes towards DFE performance.

This personal environmental commitment was measured by a single indicator: the extent to which the company's representative claimed that his personal environmental commitment was a reason to participate in the IC EcoDesign project.
Figure 7.9 shows, however, that only weak correlations are to be found. The assumption that a respondent's high personal environmental commitment contributes towards DFE performance is therefore not empirically supported.

	DFE Result					DFE Learning				
	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE result scale	DFE objec-tives	DFE involvem. extern	DFE aware-ness	DFE specifi-cation	DFE learning scale
Commitment/ attitude										
Personal environm. commitment, v074, r	0.02 (71)	0.00 (71)	0.02 (73)	0.10 (72)	-0.01 (70)	0.05 (52)	-0.08 (66)	0.23 (71)	0.09 (47)	0.18 (37)
Personal DFE attitude, v187, r	0.13 (72)	0.06 (72)	0.22 (75)	**0.41 (74)**	0.24 (71)	**0.40 (54)**	**0.28 (67)**	**0.52 (72)**	**0.50 (48)**	**0.57 (37)**
Additional variables:										
Appreciation IC project, v188, r	-0.08 (72)	0.03 (72)	0.04 (75)	**0.42 (74)**	0.15 (71)	-0.10 (54)	0.17 (67)	**0.44 (72)**	0.16 (48)	0.21 (37)
Opinion: concrete results v189, r	**0.33 (71)**	**0.43 (71)**	**0.64 (74)**	--	**0.70 (71)**	0.09 (53)	**0.38 (66)**	**0.56 (71)**	0.16 (47)	**0.38 (36)**
Recommends others to participate, v190, r	0.03 (70)	0.12 (70)	**0.28 (72)**	**0.54 (71)**	**0.31 (69)**	-0.01 (52)	0.20 (66)	**0.41 (70)**	0.07 (46)	0.15 (37)
Continue to use scan, v191, r	**0.35 (65)**	**0.44 (65)**	**0.52 (68)**	**0.69 (67)**	**0.57 (64)**	0.18 (48)	0.19 (61)	**0.62 (66)**	0.20 (46)	**0.33 (37)**
Position of respondent v185, r	**0.30 (71)**	**0.30 (71)**	0.12 (74)	0.23 (73)	**0.28 (70)**	0.20 (53)	0.03 (67)	**0.32 (72)**	0.16 (48)	**0.27 (37)**

Figure 7.9 Correlation coefficients (Spearman's r or η) between respondent characteristics and the company's DFE result and DFE learning

Hypothesis 5.B If the company's representative has a positive attitude towards DFE, DFE performance will be higher than in case he has a critical attitude.

The attitude of the company's representative towards DFE is measured by the extent to which he claims to have a 'very active' or a 'rejecting' attitude towards DFE. Conform our expectation, Figure 7.9 shows considerable correlations between this respondent characteristic and the indicators of DFE performance. The positive attitude towards DFE was obviously influenced by the good project results in terms of a high DFE performance.

Additional respondent characteristics

In a more exploratory setting attention was given to an additional set of assumptions related to respondent characteristics. First of all we investigated the relation between the respondent's

appreciation of the IC EcoDesign project and the company's DFE performance. The level of appreciation was measured on the basis of four indicators: the degree of personal appreciation (as a score), the extent to which the project led to concrete results, the extent to which the respondent would recommend the project to other SMEs, and the extent to which the respondent planned to continue to use elements of the Environmental Innovation Scan. Figure 7.9 shows some considerable correlations and thereby gives empirical support to the assumption that if a company's respondent is highly appreciative of the IC EcoDesign project, then the company's DFE performance would be relatively high as well. This is not surprising, since a company with a high DFE performance will probably appreciate the IC EcoDesign project.
The final respondent characteristic explored was the ***respondent's position***. The expectation was that if the respondent is the company's owner-manager he will have the power to take the decision to act as a change agent. DFE performance will therefore be higher than if the respondent only has limited powers of decision. Further analysis of the research data supported this assumption.

The empirical findings support hypothesis 5.B. As expected, respondents holding a positive attitude towards DFE, and who highly appreciate the (results of the) IC EcoDesign project, are employed by companies with a relatively high DFE performance.
Furthermore, the respondent's position seems to be correlated with the DFE performance of the company involved. If the respondent was the company's owner-manager, DFE performance was relatively high.

7.3.5 Intervention characteristics; reflecting on hypothesis 6

Chapter 4 formulated the assumption that if the IC consultant performed the Environmental Innovation Scan at the moment the company had high innovational ambitions, the result of the intervention (in terms of DFE performance) would be high. This assumption is represented by hypothesis 6 which is reflected on in the following section.

Hypothesis 6 **Only if a consultant enters a company at such a time when the company's innovative ambitions are high, will the intervention lead to a high level of DFE performance.**

The innovational ambitions of a company at the moment of intervention was measured by two indicators. The first was the R&D planning for the product concerned: if there were plans to redesign the product, or it was being redesigned at the moment of intervention, the momentary innovational ambitions were high. Figure 7.10 shows the coefficients for correlation between this indicator and the DFE performance indicators.

	DFE Result					DFE Learning				
	DFE score	DFE project score	DFE design impact	DFE result opinion	DFE result scale	DFE objec-tives	DFE involvem. extern	DFE aware-ness	DFE specifi-cation	DFE learning scale
Innovational ambitions:										
Product development plans, v008, η	0.32 (71)	0.41 (71)	0.39 (74)	0.56 (73)	0.49 (70)	0.42 (53)	0.34 (66)	0.38 (71)	0.28 (47)	0.26 (36)
Product ready for re-design, v0014s4, η	0.44 (74)	0.47 (74)	0.31 (77)	0.25 (74)	0.47 (71)	0.06 (54)	0.02 (67)	0.16 (72)	0.02 (48)	0.02 (37)
Additional variables:										
Participation because of subsidies, v086, r	-0.03 (72)	0.15 (72)	0.10 (74)	0.35 (73)	0.21 (71)	0.02 (53)	0.25 (67)	0.07 (72)	0.11 (47)	0.15 (37)
Wants to please IC consultant, v087, r	-0.08 (69)	-0.15 (69)	-0.26 (72)	-0.29 (71)	-0.20 (68)	-0.02 (51)	-0.24 (64)	-0.05 (69)	0.03 (46)	-0.06 (35)
Innovation Centre involved, v197ic, η	0.47 (74)	0.50 (74)	0.51 (77)	0.61 (74)	0.61 (71)	0.54 (54)	0.57 (67)	0.54 (72)	0.41 (48)	0.62 (37)
IC consultant involved, v198con, η	0.57 (74)	0.57 (74)	0.60 (77)	0.69 (74)	0.74 (71)	0.54 (54)	0.59 (67)	0.58 (72)	0.47 (48)	0.65 (37)

Figure 7.10 *Correlation coefficients (Spearman's r or η) between intervention characteristics and indicators for DFE result and DFE learning*

The fact that the indicator shows a significant correlation with all ten indicators of DFE performance leads to the conclusion that the 'momentary innovational ambitions' are indeed a good predictor for high DFE performance. Conform expectations, the highest DFE performances were achieved if there were plans to redesign the product within the near future. This conclusion is supported by the second indicator of a company's momentary innovational ambitions. This indicator related to the question whether or not the specific product had been selected because it was ready for a (major) redesign, thus revealing a high innovational ambition.

Additional intervention characteristics

In an explorative setting the impacts of some other intervention characteristics were also investigated. The first was whether a company had participated in the IC EcoDesign project because of the related, subsidiary system. Figure 7.10 shows that this characteristic bears only little relation on the resulting DFE performance. More interesting was the question to what extent had companies participated in the IC EcoDesign project because their representative had not wanted to disappoint the IC consultant. The correlations calculated indicate an inverse relationship between this reason for participation and the resulting DFE performance. Obviously, this motivation is not a solid basis for participation.

Unexpectedly high were the correlations calculated, implying a relationship between a company's DFE performance and the specific Innovation Centre (IC) and IC consultant involved in the company's case. Correlation between IC consultant and DFE performance indicators is particularly high. This leads to the conclusion that a company's DFE performance partly depends on the IC consultant involved. Whether this is due to differences in knowledge, consulting styles, DFE commitment, or other personal factors, is a subject for further study.

The following conclusions can be drawn with regard to the relationship between intervention characteristics and the resulting DFE performance. A convincing predictor for a company's DFE performance would seem to be its 'momentary innovational ambitions'. If the company has the ambition to redesign a specific product at the moment the Environmental Innovation Scan is performed, the likelihood of a significant DFE performance is high. The influence of the individual IC consultants on the DFE performance of the company is also important. Whether this depends on the consultant's knowledge, consulting style, or attitude towards DFE, is a subject for further study.

7.3.6 Answering research question B

Do all the empirical findings presented above finally lead to an answer to the second central research question of this thesis? This second central research question, the basis for research model B, was: *Can we explain the differences in the SMEs' DFE performance as a result of the IC EcoDesign project?* Yes, to a certain extent, as the following conclusions will show.

A company's DFE performance was measured according to three indicators DFE focus, DFE result and DFE learning. Chapter 5 revealed that companies differed quite substantially in respect of these three DFE performance indicators. The various indicators operationalizing DFE result and DFE learning could be aggregated into a limited set of ordinal dependent variables, thus facilitating bivariate statistical analyses of the relation between these dependent variables and a large set of explanatory variables.
We know that the companies differ considerably in terms of their DFE focus: they could be grouped into eight different DFE focus clusters on the basis of their similarities in terms of number and type of DFE options they had prioritized. However, due to the limited number of cases we were unable to explain why certain companies share a specific DFE focus. This limits our chances of giving a complete answer to the research question above. We are, however, able to answer it sufficiently if we transform the question to: *Can we explain the differences in the SMEs' DFE result and DFE learning, as a result of the IC EcoDesign project?*

Regarding this question we may conclude (on the basis of the empirical findings set out in the above) that we were indeed able to identify several characteristics which seem to be correlated with a company's DFE result and DFE learning. These characteristics were clustered into four groups:

company characteristics, product characteristics, respondent characteristics and intervention characteristics.

A total of 59 explanatory variables were found to be convincingly correlated with the dependent variables DFE result *and/or* DFE learning. Most of these 59 characteristics had a significant correlation with both dependent variables, DFE result *and* DFE learning. However, 8 of these 59 explanatory variables correlated to a sufficient extent to DFE result only.
A further 22 of the 59 variables showed a convincing correlation with the indicators of DFE learning only. As many as 12 of these 22 variables correlated with DFE learning were factors which revealed a strong external pressures to apply DFE to the product in question (referred to as product characteristics). Examples of these variables are 'the DFE attitude' of customers or end users and 'the DFE stimulus' due to customers, end users, retailers, consumer organizations or suppliers. It would seem that while this external pressure resulted in some companies intending to apply DFE to their products, they had not yet achieved any concrete product improvements.

As a final conclusion, the 30 explanatory variables which showed a convincing correlation (Spearman's r or _ various times 0.25 or higher), with respect to DFE result *and* DFE learning indicators are summarized in Figure 7.11 below.

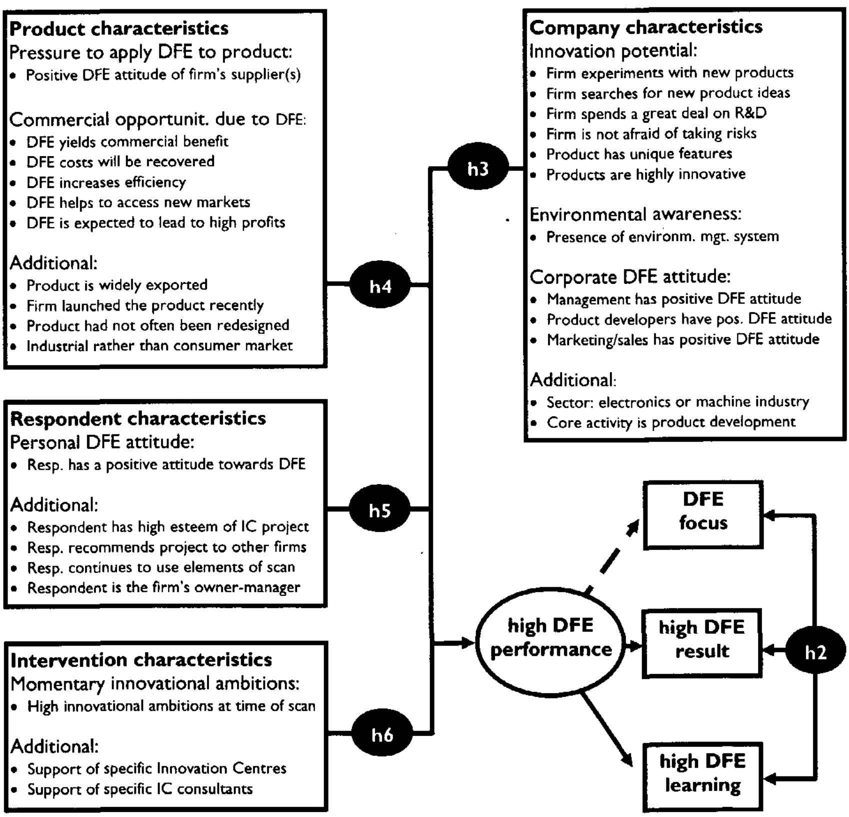


Figure 7.11 *The partial research model B with hypotheses 2 to 6; the explanatory variables included correlate convincingly with the dependent variables DFE result and DFE learning*

8. Conclusions, reflection and recommendations

Chapter 8 concludes the thesis. It first summarizes and subsequently reflects on the conclusions derived from the preceding chapters. The reflections lead to a range of recommendations, starting with a set of suggestions for further research related to the subject of DFE. The chapter is concluded with recommendations on how to enhance the implementation of Design for Environment in industry.

8.1 Introduction

The objective of the study reported in this PhD-thesis was to learn more about how small and medium sized enterprises (SMEs) cope with Design for Environment (DFE) in their product development. Two central research questions were formulated:

A. Why are certain product improvement directions within the field of Design for Environment more successful than others?

B. Why do some SMEs perform well in Design for Environment while others lag behind?

In order to study these questions a conceptual research model, plus a specific research methodology were developed. The conceptual research model distinguishes research model A and research model B, reflecting the twofold aim of this study.

Finding answers to these questions means gaining insights that could help remove certain barriers and stimulate SMEs to develop cleaner products. The focus in this study was on small companies since the DFE efforts in this sector had hardly been studied before. However, the small company sector has a large part to play in the industrial activities under way in the Netherlands.

In 1995 a group of 94 SMEs participated in a large scale EcoDesign project coordinated and executed by the Innovation Centres (ICs) of the Innovation Centre Network in the Netherlands (ICNN). Of these, 77 were included in the study reported in this thesis. The requirements for participation in this IC EcoDesign project were that the companies employed no more than 200 people, and that they were 'self-specifying', meaning that they autonomously define the products' specifications. The aim of the IC EcoDesign project was to raise awareness about EcoDesign in small and medium sized enterprises and to support them in applying EcoDesign (or Design for Environment) principles to their own products. The IC EcoDesign project therefore presented the opportunity to empirically explore the questions on the application of DFE in the small company sector. The preceding seven chapters led, step-by-step, to the answers we sought.

In this final chapter we will summarize the main conclusions of the study and also elaborate them into recommendations. The most important conclusions of this PhD study (reported in Chapters 1 to 7) are summarized in Section 8.2 and Section 8.3. These sections focus on the empirical findings rather than the methodological procedures that were applied.

Furthermore, having almost reached the end of this study there is an urge to reflect on what has been achieved by this PhD thesis. Has the study taught us what we wanted to learn? To what extent will the research methods that were developed and used in this specific study be of use in other studies? Which research questions are worth studying in more detail in future research? Questions like these are reflected upon in Section 8.4. These observations finally lead to a set of recommendations for the further enhancement of Design for Environment in industry. These are presented in Section 8.5.

8.2 Conclusions regarding the success of DFE principles

This section summarizes the conclusions of this thesis related to research question A. In order to assess and explain the success of the various DFE improvement options, referred to as DFE principles, answers were sought for the following:

A.1 How can we measure the success of DFE principles?

A.2 What is the variance in success rate amongst various DFE principles?

A.3 How can the assumed variance in success rate amongst DFE principles be explained?

The following presents the findings of this research.

8.2.1 Measuring the success of DFE principles

To answer research question A.1, a typology of all the potential DFE strategies and principles was developed, enabling the typification of all DFE improvement options that had been studied. The resulting typology of DFE strategies and DFE principles (which was optimized further during the course of the study) formed the fundament for a model called the DFE strategy wheel. This typology distinguishes 33 so-called DFE principles, possible ways to improve the environmental profile of a product system, taking all the stages of its life cycle into consideration. These 33 DFE principles were a priori clustered into 8 DFE strategies based on literature analysis and the initial DFE experiences. Initially, the DFE strategy wheel was only meant to function as a frame of reference for the researcher, giving an overview of possible ways to improve the environmental product profile, embodied in the expression 'Design for Environment'. Later on the DFE strategy wheel also played a substantial role in the Environmental Innovation Scan, the auditing method developed by the Innovation Centre Network for the IC EcoDesign project. The DFE strategy wheel is illustrated in Figure 2.2 (Chapter 2). The DFE typology was used in this study to facilitate typification of the so-called 'DFE improvement options' suggested by the IC consultant in a company DFE action plan.

Success rates

Each DFE improvement option was then evaluated during interviews by telephone with the participating companies. This evaluation was necessary in order to find out the degree to which a company had managed to implement its specific DFE improvement options. Nine so called 'success rates' were distinguished as listed in Figure 3.5 in Chapter 3.

By means of the DFE typology, plus the distinction of nine success rates, it was possible to answer research question A.2 which related to:
- Which DFE principles were the ones most frequently suggested by the IC consultants;
- Which DFE principles were the most successful, meaning that a large share of DFE options of the type of DFE principle had been prioritized.

8.2.2 The success of DFE principles

In the first phase of the IC EcoDesign project a total of 596 DFE improvement options had been suggested for the 77 companies investigated in this research project. The companies indicated that of the 596 suggested DFE options, a total of 247 (41%) had been ***prioritized*** (these options had been classified with a success rate of 4, 5 or 6). 'Prioritized' here means that the DFE option had either been realized or would be realized within a three-year period. This was ascertained 1 ½ year after the companies had entered the IC EcoDesign project. These DFE options would therefore be realized within 4 ½ years of having received the EcoDesign advice. Of the 247 DFE improvement options prioritized, 183 (74% of 247; 31% of 596) had already been ***realized*** (attributed with success rate 6). 'Realized' here means that the DFE improvement option had already been implemented in the product design; the redesigned product had already been launched or 'would certainly' be launched in the near future. These percentages equal the results of the preceding, successful PRISMA project. Furthermore, as many as 60 companies had prioritized at least one DFE improvement option. This means that the IC EcoDesign project had boosted DFE awareness and activities in a large number of the participating companies.

The typification of the DFE options showed considerable differences among the 33 DFE principles distinguished. Some DFE principles had been suggested more frequently than others. Furthermore, we found considerable differences in the amount of success of these 33 DFE principles. The ten DFE principles that proved to be most successful are listed in Figure 8.1 below.

DFE principle	Description	% of DFE options prioritized	Suggestion frequency
7.3	Recycling of materials	47%	77
6.1	High reliability/durability	45%	38
1.4	Recycled materials	45%	20
5.1	Low energy consumption	44%	34
7.2	Remanufacturing/refurbishing	42%	19
3.4	Less production waste	38%	24
3.1	'Clean' production techniques	38%	20
2.1	Reduction in weight	37%	79
1.1	'Clean' materials	28%	72
4.1	Less/'clean'/reusable packaging	26%	27

Figure 8.1 *The percentages of DFE options prioritized and the suggestion frequency for the ten most successful types of DFE principle*

Figure 8.1 ranks the DFE principles according to their success, expressed as the percentage of DFE options prioritized (success rate 4, 5 or 6), and compared with the total number of DFE options of the specific type of DFE principle that had been suggested. The companies studied seem to spend most attention to end-of-life issues (recycling of materials, remanufacturing/refurbishing), reducing product weight and the use of 'clean' (non-hazardous) and recycled materials. Other important topics were increasing product durability, reducing the product's energy consumption and cleaner technology (less production waste and 'clean' production techniques). Finally, the product's packaging was felt to be of great environmental concern as well. The figure also shows that the ten most successful DFE principles were also the ten most frequently suggested DFE principles (albeit in a different order). A comparison of these results with the conclusions of other studies (Smith et al., 1996; Hanssen, 1997) showed that the following DFE principles were dominant in the Netherlands, the UK and the Nordic countries: Recycling of materials and Selection of 'clean' materials.

In addition, six DFE principles were found to be successful, although they had not been suggested frequently. These DFE principles are listed in Figure 8.2 below. Each DFE strategy is represented in Figure 8.1 or Figure 8.2, with one exception: DFE strategy @, New concept development. This strategy can be regarded as the least successful one.

DFE principle	Description	% of DFE options prioritized	Suggestion frequency
3.2	Few production steps	60%	5
3.3	Low/'clean' production energy	60%	10
6.2	Easy maintenance/repair	58%	12
6.3	Modular/adaptable structure	56%	9
4.3	Energy efficient logistics	50%	8
3.5	Few/'clean' production consumables	44%	9

Figure 8.2 *DFE principles that were prioritized relatively often, but not frequently suggested*

8.2.3 Understanding the differences in the amount of success of the DFE principles

Are we able to understand why certain DFE principles are more successful than others? The approach chosen to answer this research question, A.3, was based on the assumption that the success of a DFE principle depends very much on the specific stimuli and barriers the companies perceive with regard to DFE improvement options belonging to the specific DFE principle.
Based on literature, three sets of factors were distinguished which are assumed will influence a company in its decision to either realize or reject a certain DFE improvement option: external stimuli (see Figure 4.5), internal stimuli (see Figure 4.6) and barriers (see Figure 4.8). During an interview by telephone the company's representative was prompted to mention all external and internal stimuli and barriers he or she perceived for each DFE improvement option that had been suggested in its DFE action plan.

Research findings

The conclusions of the analysis reported in detail in Chapter 6 are summarized in Figure 8.3 below, revealing the most often mentioned and the most influential external stimuli, internal stimuli and barriers.

	External stimuli	Internal stimuli	Barriers
Total number?	130	795	414
For how many of the 596 DFE options?	111 (19%)	339 (62%)	322 (54%)
Which stimuli/barriers were the most frequently mentioned?	1. Customer demands (56) 2. Government regulation (43) 3. Supplier developments (16)	1. Environmental benefit (201) 2. Cost reduction (177) 3. Image improvement (102)	1. Conflict with functional requirem. (108) 2. No distinct environmental benefit (51) 3. Commercial disadvantage (51)
Which stimuli/barriers have the most influence?	1. Customer demands 2. Government regulation 3. Branch of industry initiatives	1. Innovational opportunities 2. Increase of product quality 3. New market opportunities	1. Not perceived as responsibility 2. No distinct environmental benefit 3. No alternative solution available

Figure 8.3 *Overview of the number of stimuli/barriers mentioned, the number of DFE options involved, and the top three types of stimulus/barrier, according to the frequency at which they were mentioned, and their relative influence*

Figure 8.3 shows clearly that the SMEs studied perceived much more internal stimuli than external stimuli: 795 internal stimuli were mentioned for 339 out of 596 DFE options (62%), whereas only 130 external stimuli were recorded for as few as 111 out of 596 DFE options (19%). Further study revealed than internal stimuli were not only mentioned more often than external stimuli, but that they had a stronger influence on the success rates of DFE options as well.

Figure 8.4 recalls the empirical findings with regard to research question A.3, including the most influential stimuli and barriers, as well as the ten most successful DFE principles.

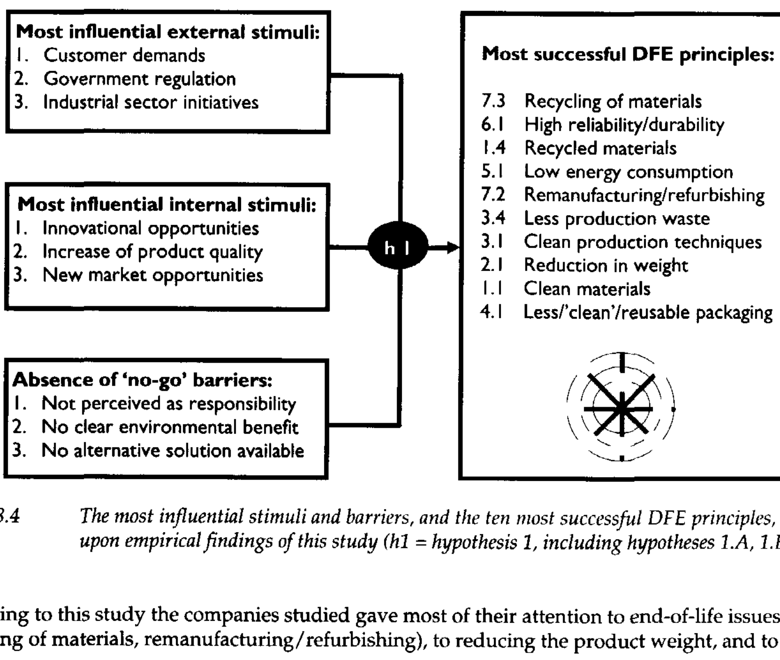


Figure 8.4 *The most influential stimuli and barriers, and the ten most successful DFE principles, based upon empirical findings of this study (h1 = hypothesis 1, including hypotheses 1.A, 1.B, 1.C)*

According to this study the companies studied gave most of their attention to end-of-life issues (recycling of materials, remanufacturing/refurbishing), to reducing the product weight, and to the use of 'clean' (non-hazardous) and recycled materials. Other important topics were the increase of product durability, reducing the product's energy consumption and cleaner technology (less production waste and 'clean' production techniques). Finally, product packaging was also an important environmental concern.

Figure 8.4 shows further that, according to this study, the most influential internal stimuli were the innovational opportunities of a DFE option, an expected increase of product quality and potential new market opportunities. Personal environmental commitment, assumed to be an influential driver for implementation of DFE option, seemed to be of little importance. The research made very clear that far out the most important external stimuli for DFE are customer demands and governmental legislation. Furthermore, this study revealed that three of the eleven barriers distinguished must be characterized as 'no-go' barriers: their presence blocks the implementation of the DFE options concerned. The other eight barriers proved to be only 'initial' barriers. If driven by a number of influential stimuli, DFE options with an initial barrier were nevertheless implemented.

.2.4 Reflection on hypothesis I

The following three hypotheses, related to research model A, were reflected upon:

Hypothesis I.A: Regarding the application of DFE in small and medium-sized enterprises, the actual influence of internal stimuli on the success rate of DFE principles is stronger than the influence of external stimuli. (Confirmed)

Hypothesis 1.A, which opposes the traditional line of thought in environmental management literature, was supported by the empirical findings of this study. In order to measure the influence of the various stimuli an assessment was made of the relation between specific stimuli a company perceived for a certain DFE improvement option and the success rate of that option. The subsequent analyses of empirical findings, reported in Chapter 6, showed that internal stimuli seem to have a greater impact on the success rate of DFE improvement options than external stimuli in the companies' decision-making on the subject of DFE.

The only external stimuli of importance that were mentioned in this study were 'legislation' and the 'environmental demands of customers and end-users'. Yet the actual number of times these external stimuli were mentioned was limited. As a consequence, the actual influence of external stimuli on SMEs is small. Furthermore, the study showed that the SMEs had usually realized DFE options that well matched their more traditional commercial values in product development. This is in line with the empirical findings of Smith et al. (1996) who found that companies that were proactive in terms of DFE did not set out to produce a 'greener' product. The companies took environmental factors into account 'in pursuit of commercial aims'. However, if we wish to stimulate SMEs to apply DFE principles that go beyond direct commercial concerns, strong and consistent external stimuli would seem to be prerequisite.

Hypothesis I.B: Of all the internal stimuli that motivate an SME to implement DFE improvements, the personal environmental commitment of that company's owner-manager is the most influential factor. (Not confirmed)

Contrary to our expectations, the empirical findings did not support hypothesis 1.B. The analysis of the relation between the internal stimuli mentioned in connection with DFE options and their success rates showed that many of these options were still rejected despite the fact that the respondent was convinced of their environmental benefit. Only when they were supported by additional stimuli did the DFE options have a chance. The study showed that the most influential internal stimuli were 'innovative opportunities', 'increase of product quality' and 'new market opportunities'. This result is similar to a conclusion drawn by Smith et al. (1996) who found that improvements in environmental performance only became a significant competitive factor once high levels of product performance, quality and value were attained. Nevertheless, research findings in Chapter 7 showed that personal environmental commitment was an important driver for a company to consider the application of DFE by participating in the IC EcoDesign project. However, in terms of decision-making on whether or not to realize DFE options, the impact of this stimulus seems to be limited.

Hypothesis 1.C: The participants in the DFE EcoDesign project will reject DFE improvement options that are susceptible to the barriers 'insufficient complementarity', 'lack of interesting technological options' and 'insufficient appropriability'. (Not confirmed)

Hypothesis 1.C reflects the expectation derived from the capability theory (Den Hond, 1996), that DFE improvement options must meet at least three requirements in order to become eligible for realization. First, the theory says a DFE option must be complementary to existing product requirements. Secondly, a DFE option will only prioritized if technological options (alternative solutions for the relevant environmental problem) already exist or if the company is interested in developing this technology itself. The third prerequisite for a DFE option to be prioritized is called 'appropriability': the DFE option must result in a commercial advantage that the company can appropriate.
The empirical findings do not support hypothesis 1.C as a whole. Insufficient complementarity and insufficient appropriability were apparently only 'initial barriers'. They were frequently mentioned, but they were not insuperable: their occurrence did not automatically block the realization of the DFE improvement concerned. Only the availability of suitable technological alternative solutions was a 'no-go barrier'. DFE options associated with this barrier were rejected or postponed for several years.
In addition to this no-go barrier, two other barriers (not mentioned in hypothesis 1.C) are prerequisites for realizing a DFE option. These additional two 'no-go' barriers can be described as 'doubting the environmental benefit of the DFE option', and 'not feeling responsible for realization of the DFE option'.

8.3 Conclusions regarding the DFE performance of SMEs

This section summarizes the conclusions of this thesis related to research question B: Why do certain SMEs perform well in Design for Environment while others lag behind? In order to assess and explain the DFE performance of the participating companies, answers had been sought to the following three questions:

B.1 *How can we measure the DFE performance of a participating company?*
B.2 *What are the differences in DFE performance among the participating companies?*
B.3 *How can the expected differences in DFE performance among the participating companies be explained?*

The following presents the research findings related to these three questions.

8.3.1 Measuring a company's DFE performance

To answer research question B.1, an instrument was developed distinguishing three elements of DFE performance: DFE focus, DFE result and DFE learning. Combined, these three dependent variables give a qualitative and quantitative impression of the DFE performance of the individual SMEs participating in the IC EcoDesign project. The measurement instrument can be said to be 'process-based'; its objective is to measure the process of change towards DFE in a company. Both for practical and theoretical reasons the study abstained from recording product modifications in environmental terms (e.g. by means of life cycle analyses).

DFE focus

A company's DFE focus refers to the type and number of DFE principles it has prioritized. 'Prioritized' means that the company, during a telephone interview, had attributed the DFE option with a success rate of 4, 5 or 6, implying that the option had already been realized or would be realized within three years after the monitoring procedure. The DFE strategy wheel typology of DFE strategies and principles (see Figure 2.2 in Chapter 2) was used to identify and typify the DFE principle of the DFE options that had been prioritized.

DFE result

A company's DFE result refers to the actual environmental product, process or packaging modifications it had accomplished. This was recorded during an interview by telephone. Four DFE result indicators were constructed; combined, they indicated the extent to which a company had managed to realize the DFE options suggested by the IC consultant. The four DFE result indicators are:

- DFE score: the extent to which a set of DFE improvement options, generated through the IC EcoDesign scan, had been realized;
- DFE project score: the extent to which a set of DFE improvement options with a high level of newness, generated through the IC EcoDesign scan, had been realized;
- DFE design impact: the researcher's opinion about the extent to which the product involved in the IC EcoDesign scan had been innovated;
- DFE result opinion: the opinion of the company's representative as to the extent to which the IC EcoDesign project had led to concrete results for the product in question.

DFE learning

A company's DFE learning reflects the extent to which the company is able to use DFE in future development projects. Initially, DFE learning was operationalized according to 47 different variables grouped into nine aspects of DFE learning (see Figure 3.14). By means of Cronbach's α nine indicators could be constructed from these 47 variables. For pragmatic reasons, four indicators were selected to act as dependent variables in further bivariate analyses:

- DFE objectives: the extent to which a company internalizes DFE in its product development procedures by setting DFE objectives;
- DFE involvement of external parties: the extent to which a company cooperated with or undertook an involvement with parties outside the company in connection with DFE;
- DFE awareness: the extent to which a company increased its knowledge (related to DFE in general and certain DFE subjects in particular);
- DFE specification: the extent to which DFE issues are specified in terms of procurement, outsourcing and cost estimates for customers.

In the following, these indicators of DFE result and DFE learning will be used to present the companies' DFE performance.

.3.2 The DFE performance of the participating companies

The following summarizes the empirical findings with respect to research question 2.B.

DFE focus

A hierarchical cluster analysis was used to group the 60 companies that had prioritized at least one DFE option into so called 'DFE focus clusters'. This was achieved on the basis of their focus with regard to DFE: the number and type of DFE principle of the DFE improvement options they had prioritized. By means of statistical cluster analysis eight DFE focus clusters could be distinguished; each cluster consists of companies with (to a limited extent) comparable DFE foci.

DFE result

- About half of all the companies shared a relatively low ***DFE score*** and ***DFE project score***. The scores of the other half were considerably higher. Two companies had achieved exceptionally high scores. This means that, as we had expected, the SMEs participating in the IC EcoDesign project differed considerably regarding the extent to which they had implemented those DFE improvement options that had been generated as a result of the EcoDesign project.
- The companies also differed considerably with regard to ***DFE design impact***. A 'major redesign' was recorded in 21 cases. This high DFE design impact was mainly achieved due to the impact of the set of DFE improvement options that had been prioritized by the companies. Although we did not measure the DFE result in quantitative, environmental terms for each company, these findings indicate that in at least 21 companies considerable environmental product improvements were achieved. Only in 5 cases had the EcoDesign project failed to lead to product improvements or research. In conclusion, the IC project had a considerable impact on the product, packaging and process designs involved.
- With regard to the ***DFE result opinion***, 48 out of 74 companies said that the IC EcoDesign project had resulted in moderate to high concrete results. Only 8 of the 74 companies said that the project had not led to any concrete result at all. The companies' appreciation of the project was thus 'fairly

high'. The researchers' opinion about the result of the IC EcoDesign project in a certain company (DFE design impact) was in line with those of the companies themselves (DFE result opinion).

A cluster analysis was then carried out to group the companies into ten clusters on the basis of similar response profiles regarding the four DFE result indicators. Each cluster included companies with a typical DFE result, ranging from 'poor DFE result' to 'very high DFE result'. Seven exceptional cases were identified in the sense that they revealed remarkable inconsistencies in their response profiles with regard to the four DFE result indicators. The analysis showed that a ranking based solely on the DFE score gave a different picture than a ranking based on a combination of DFE project score, DFE design impact and DFE result opinion. The preferred ranking reflects the extent to which the IC EcoDesign project was actually a success for a specific company. It therefore emphasizes the DFE project score, the DFE design impact and the DFE result opinion, at the cost of the DFE score indicator.

DFE learning

The last indicator of DFE performance was a company's DFE learning, focusing on the extent to which the project had led to organizational or procedural changes in a company, and thus facilitating the utilization of DFE in future projects. DFE learning was operationalized by 47 different variables, later combined into the nine DFE learning indicators mentioned below. The companies' DFE performance in terms of DFE learning was as follows.

- **DFE policy**: Only a few companies studied stated their intention to communicate their DFE policy or initiatives by means of written, public documents.
- **DFE objectives**: As many as 33 companies claimed they made use of environmental concerns 'sometimes' to 'very often' in their product planning procedures. Moreover, 37 companies said to integrate environmental concerns in their in-house product specifications, ranging from 'sometimes' to 'very often'.
- ***DFE management system integration***: Many companies said they assigned DFE responsibilities to certain employees. Also remarkably high was the number of companies that mentioned the incorporation of DFE aspects in their quality system. Many of the companies with a (usually informal) EMS said that it was their intention to create a link between DFE and their EMS.
- ***DFE internal involvement***: It was usually only one person that participated in the project. Nevertheless, in many cases the project was discussed at management level; it was relatively often discussed with in-house product developers, the marketing/sales department and the production department. The persons responsible for environmental issues were not always involved in the project, probably because up to then they had only focused on production issues. Quality managers were involved somewhat more frequently, probably because their activities relate more directly to the design of the product.
- ***DFE involvement of external bodies***: Most of the companies investigated hardly ever cooperated - regarding DFE - with other companies in the product supply chain, and even less in their own branch of industry. Slightly higher were the scores for cooperating with knowledge institutes. The companies discuss DFE issues regularly with their customers, more often than with recyclers.
- ***DFE awareness***: A particularly high increase was seen in DFE knowledge in general, in knowledge about environmental aspects of the materials applied, and in knowledge about the environmental bottlenecks in product life cycles. This means that the IC EcoDesign project had substantially increased corporate knowledge in the field of ecodesign.
- ***DFE follow-up activities***: Only 21 companies made use of the opportunity to obtain support from an external consultancy for a feasibility study of the newly learned DFE options that had been suggested. In addition, 14 companies that had not requested external support reported that they had calculated the costs of the DFE options. This can also be regarded as an initial feasibility study. Remarkably often companies had already applied DFE principles to other products. Many companies planned to use DFE principles in future product development. Very few companies had used specific DFE-related software, indicating that SMEs are not particularly keen on using software tools for DFE.
- ***DFE specification***: With exceptions, the companies studied hardly specify DFE concerns in procurement procedures, when outsourcing production or development and in cost estimates for customers. Comparing these four situations, DFE requirements are the most explicitly specified when outsourcing product development and in procurement.

- ***DFE protocol***: As many as 17 companies had developed some sort of DFE checklist, and three companies had produced a DFE manual. Only 7 companies had asked a supplier to sign a toxics-free declaration; 11 companies had placed a supplier under the obligation to take their products back. For SMEs these results are not disappointing.

DFE learning was the ***highest*** regarding the following aspects:
- DFE objectives (integrating DFE in in-house product planning procedures);
- DFE management system integration (especially linking DFE to existing EMS or QS);
- DFE internal involvement (involvement of management and product developers);
- DFE awareness (increase of DFE-related knowledge);
- DFE follow-up activities (especially regarding the utilization of DFE experience for other products);
- DFE protocol (especially in terms of using a DFE checklist).

DFE learning was ***low*** in terms of:
- DFE policy (the companies hardly communicated their DFE initiatives in public documents);
- DFE external involvement (the companies hardly established DFE cooperation with external parties);
- DFE specification (companies hardly specified DFE requirements in connection with external parties).

Later on, four of these nine DFE learning indicators were selected and combined into one, overall scale for DFE learning. The diverging scores on this scale emphasized that the companies did indeed differ considerably regarding the organizational or procedural changes they had accomplished.
We also found that while the scores for the four DFE learning indicators were relatively low in general, they still showed a strong variance. This strong variance indicates that we should refrain from drawing conclusions for SMEs in general, or to be extremely careful when doing so.
The empirical findings presented here do not reveal what the various aspects of DFE learning (like DFE checklists, follow-up activities) look like exactly, or how intensively they are applied in development practice. These are interesting subjects for future study.

8.3.3 Understanding the differences in the companies' DFE performance

In order to answer research question B.3, ~~the~~ differences in company DFE performance was explained by means of four sets of variables: characteristics related to the company, the product, the respondent and the intervention method used. The relation between these characteristics (as explanatory variables) and the companies' DFE result and DFE learning were assessed by means of a range of statistical bivariate correlation analyses. The relation between a company's DFE focus and the explanatory variables was left out of further consideration. DFE focus is a nominal variable; the number of companies included in the analyses was too small to yield reliable results.
A total of 59 explanatory variables distinguished showed a substantial correlation with the companies' DFE result and/or their DFE learning. About half of these 59 variables correlated significantly with the companies' DFE result *or* the companies' DFE learning. The other 30 explanatory variables which correlated with both DFE result *and* DFE learning are regarded as sufficiently convincing indicators of a company's DFE performance. These variables are summarized in Figure 8.5 below.

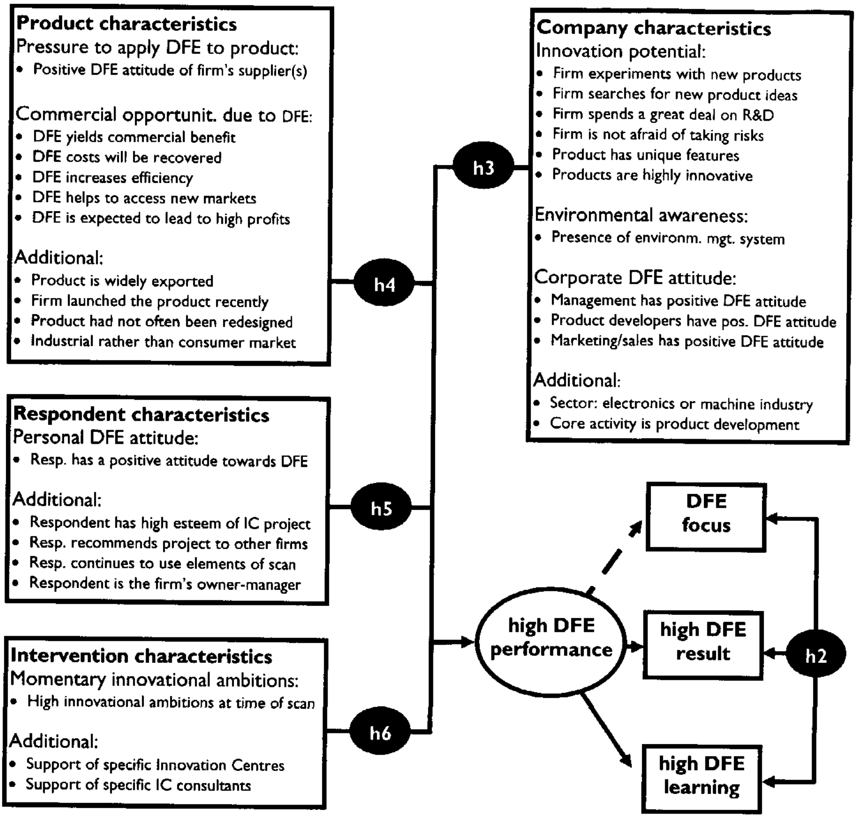


Figure 8.5 *The partial research model B with hypotheses 2 to 6 (h2 to h6); the explanatory variables included show a convincing correlation with the dependent variables DFE result and DFE learning*

Certain relations were obvious and (not entirely to our surprise) confirmed by the study. For example: it was no surprise to find a strong link between the commercial opportunities of DFE for a certain product and the DFE performance of the company concerned. With regard to certain other characteristics the empirical findings were more surprising. The more surprising findings were:

- Companies which sell their products to industrial markets seem to yield a higher DFE performance than those which focus on consumer markets. An explanation for this might be that industrial customers have more specific environmental demands than consumers.
- A company's DFE performance was the highest if the respondent was the company's owner-manager.
- The 'intervention characteristics' seem to be remarkably important. The empirical findings indicate that a company's DFE performance is strongly related to the moment of intervention as well as to the specific IC consultant involved.
- DFE performance is relatively high in innovative companies. These are companies that experiment, search actively for new product ideas, invest in R&D, dare to take risks and market products with unique product features or highly innovative products.
- Companies which had established an environmental management system (formal or informal) seemed to reveal a relatively high DFE performance.

8.3.4 Reflection on hypotheses 2 to 6

Derived from Figure 8.5 five hypotheses were defined, most of them specified by means of two or three sub-hypotheses. The following summarizes the extent to which these hypotheses were supported by the empirical findings of this study.

Hypothesis 2.A: Companies that manifest a good DFE result, as a result of the IC EcoDesign project, will also achieve a high level of DFE learning. (Confirmed)

The empirical findings of this study support hypothesis 2.A. Bivariate correlation analyses showed that the five indicators for DFE result and the five indicators for DFE learning were correlated to a moderate extent, ranging from 'slightly' to 'considerably'. This means that most companies with a high DFE result also revealed a relatively high level of DFE learning as well and vice versa. In this thesis no effort was made to study the causality of these relationships. This is an interesting topic for future study

Hypothesis 2.B: Companies that manifest a good DFE result and a high level of DFE learning as a result of the IC EcoDesign project also have a comparable DFE focus. (Confirmed)

A statistical cluster analysis showed that the companies studied could be clustered into eight 'DFE focus clusters' according to their specific DFE focus (the type and number of DFE principles they had prioritized). The findings showed considerable correlation between the variable 'DFE focus cluster' and the ten indicators for DFE result and DFE learning. As assumed, this implies that companies belonging to a specific DFE focus cluster not only have a similar DFE focus, but a comparable DFE result and DFE learning too. To enable more detailed research on this issue, identified clusters should be much more homogeneous than they were in this research. We suggest limiting the scope in future research to the implementation of DFE in a limited number of branches of industry.

Hypothesis 3.A: Companies with a high innovative potential have a higher DFE performance than less innovative companies. (Confirmed)

There is empirical evidence supporting the assumption that the more innovative a company, the higher its DFE performance. Indicators for innovativeness that showed a considerable correlation with the DFE performance indicators were 'the extent to which a company experiments', 'searches actively for new product ideas', 'invests in R&D', 'markets products with unique product features or products that are highly innovative' (new in the industry to which the company belongs). This conclusion supports the notion that DFE can create synergy with more traditional targets in product development, like high product quality, durability, consumer friendliness and process efficiency. Companies able to reach these targets in their product development generally manifest a high level of DFE performance as well. Not all indicators for innovativeness supported this hypothesis to the same extent though. Further multivariate analysis is recommended to assess the interrelations between the indicators for innovativeness that were distinguished, and to relate them to companies' DFE performance.

Hypothesis 3.B: Companies with a high level of environmental awareness and activities have a higher DFE performance than companies with less environmental awareness and fewer activities. (Not confirmed)

In general, indicators of a company's DFE awareness (e.g. pursuing an environmental policy) were weakly correlated with the indicators for DFE performance. The only exception here was the presence of an Environmental Management System, which seems to be a good predictor for a relatively high DFE performance of a company. This finding indicates that an EMS could be a stepping stone towards DFE, and vice versa. It would be interesting to study the extent to which EMS and DFE could enhance one another, especially since the recently launched Dutch programme 'Product-oriented Environmental Management' is based on this idea.

Hypothesis 3.C: Companies with a positive attitude towards DFE will manifest a higher DFE performance than companies with a critical attitude. (Confirmed)

The analysis showed that particularly the DFE attitude of the company's management, its product development department, and its marketing/sales department, are good predictors of a high DFE performance in terms of DFE result *and* DFE learning. Correlation between the other indicators of a company's DFE attitude (the DFE commitment of the environmental, quality, purchasing and production departments) and DFE performance were not sufficiently convincing to support this hypothesis. Again, the causality of the relations was not studied; it must therefore be accepted that a company's positive attitude towards DFE could be the result of the IC EcoDesign project, rather than a predictor of the company's DFE performance.

Additional findings related to company characteristics

Conclusions regarding some additional company characteristics were as follows. The empirical data showed substantial correlation between the ***branch of industry*** to which the company belongs and its DFE performance. This implies that DFE performance depends partly on the company's branch of industry. The most DFE-active industries would seem to be the electronics industry and the machine industry. Another predictor of high DFE performance is a company's ***core activity***; if a company regards product development as one of its core activities, then its DFE performance is generally high in terms of both DFE result and DFE learning. The few companies studied that are 'jobbers' or wholesalers seemed to feel less responsibility for DFE and generally wait for initiatives to be taken by companies positioned nearer to the source of the product supply chain.

Another often-heard assumption is that a company's DFE performance depends on ***size***. In the study reported here we found that company size (in terms of number of employees) bears no relation with its DFE performance. Hence, the empirical studies on the subject all seem to report contradicting conclusions. In order to understand this we think a more clear distinction should be made between the actual type of environmental initiatives studied. Subjects like the implementation of EMS and cleaning technology should be distinguished quite clearly from subjects like DFE. The first two are stimulated by standards and regulations, affecting larger companies far more than smaller ones. There are hardly any standards connected with DFE; for this reason, implementation of DFE does not depend on company size.

Hypothesis 4.A: Products subjected to external pressure with regard to their eco-efficiency will prompt a higher DFE performance than those which are not. (Confirmed)

Several sets of indicators were used to measure the amount of external pressure to implement DFE in connection with the products concerned. Remarkably, these pressures seemed to influence a company's DFE learning rather than its DFE result. We found that of all the actors that boosted a company's DFE learning, the company's customers and end-users seem to be the most influential. The empirical findings therefore support hypothesis 4.A, especially in respect of external DFE pressure from a company's customers and end-users. This is in line with our earlier conclusion that the most influential external stimuli for DFE was customer demand (see Figure 8.4). This implies that if we want to boost the use of DFE among SMEs, external pressure can help.

Hypothesis 4.B: Products for which DFE offers commercial opportunities will lead to a higher DFE performance than those for which DFE is perceived as commercially neutral or negative. (Confirmed)

This study supported hypothesis 4.B. The empirical findings revealed some convincing predictors of DFE performance. Not surprisingly, good predictors were the extent to which a company regards DFE as a commercial opportunity, an initial investment which is recovered in due course, an opportunity to increase efficiency, a means of reducing production or transport costs, or a means of increasing market shares or entrance to new markets. Very convincingly correlated are the company's DFE performance and its estimation of the total commercial gains from DFE in two years' time. These results support hypothesis 4.B. Here too should the word 'predictor' be used with great care: the causality of the relationships was not analyzed. The perceived commercial opportunities of DFE could be influenced by the result of the IC EcoDesign intervention.

Additional findings related to product characteristics

In addition to the hypotheses mentioned above, the relation between a company's DFE performance and an additional set of product characteristics was also explored. This led to some surprising findings. The DFE performance generally turned out to be the highest if the product was ***exported world-wide***, if it had been ***recently launched***, if it had ***not yet been redesigned*** (or only once), if it was in the ***growth stage*** of its commercial life cycle, if it had a short functional life time and if it was intended for an ***industrial market*** rather than the consumer or governmental market.

Hypothesis 5.A: A high personal environmental commitment on the part of the company representative contributes towards DFE performance. (Not confirmed)

Personal environmental commitment was measured by the extent to which the company's representative claimed that his personal environmental commitment was one of the reasons to participate in the IC EcoDesign project. Only a weak correlation was found between this indicator and the company's DFE performance. Therefore, assumption 5.A was not empirically supported. This finding supports our earlier conclusion - related to hypothesis 1.B - that if we wish to boost the utilization of DFE in a small company, the personal environmental commitment of the company's owner-manager is essential. However, when it comes to decision-making on the realization of DFE options, the impact of this stimulus seems to be limited.

Hypothesis 5.B: If the company's representative has a positive attitude towards DFE the DFE performance will be higher than in case he has a critical attitude. (Confirmed)

Hypothesis 5.B is evidently supported by the results of this study. In order to test it, the attitude towards DFE of the company's representative was measured by asking him whether he his attitude towards DFE was a very positive one or one of rejection. As expected, considerable correlations were found between this respondent characteristic and the indicators of DFE performance. The results may, however, have been influenced by the fact that good project results (in terms of high DFE performance) probably resulted in a positive attitude towards DFE.
The fact that, contrary to hypothesis 5.A, hypothesis 5.B is apparently supported by empirical evidence, might appear contradictory: persons with a positive attitude towards DFE are supposed to have a high level of environmental commitment as well. This contradiction is probably due to the operationalization of the two hypotheses 5.A and 5.B. The operationalization of these hypotheses by means of only one variable might have been too poor to achieve reliable conclusions.

Additional findings in connection with respondent characteristics

In addition to hypotheses 5.A and 5.B we also looked into the relationship between certain other respondent characteristics and a company's DFE performance. As expected, respondents who were highly ***appreciative*** of the (results of) IC EcoDesign project generally belonged to those companies that had a relatively high DFE performance. Furthermore, the respondent's ***position*** seems to be connected with the company's DFE performance: if the respondent was also the company's owner-manager, DFE performance was relatively high.

Hypothesis 6: Only if a consultant enters a company at such a time when the company's innovative ambitions are high, will the intervention lead to a high level of DFE performance. (Confirmed)

The empirical findings supported hypothesis 6. As assumed, a convincing predictor of a company's DFE performance seems to be its 'momentary innovational ambitions'. If the company had the ambition to redesign the product at the moment the Environmental Innovation Scan was performed, the chances of a significant DFE performance were relatively high. This corresponds with a research finding related to hypothesis 4 that if a product is in the growth stage the DFE performance is apparently higher than when going through one of the three other stages of its commercial life cycle (introduction - growth - maturity - decline). A company's momentary innovational ambitions seem to relate (along with many other factors) to the stage of the commercial life cycle a product is in at that time.

Additional findings in connection with intervention characteristics

The influence of the individual ***IC consultant*** on the company's DFE performance was also investigated. This turned out to be unexpectedly high (correlation coefficients between 0.47 and 0.74 for each of the ten DFE performance indicators). Whether this depends, for instance, on the consultant's knowledge, his or her consulting style, or attitude towards the subject of DFE, is an important subject for further study.

8.4 Reflection on the outcomes of this research

Only an initial impression of the final outcomes was foreseen at the start of the research project reported in this thesis. Several research aims and questions were articulated and explored without knowing precisely which of them were actually going to be answered in detail. At the end of the project there is the urge to look back to the research aims as articulated in the first instance. To what extent have those initial research aims been achieved? Were they achieved in an efficient way? And did the study meet the demands for environmental management research as referred to by Gladwin (1993)? The following sections look at the outcomes and methodology of this study.

8.4.1 The DFE strategy wheel

The DFE strategy wheel and its underlying typology of DFE strategies and principles played an important role in this study. It offers a frame of reference and a communication structure, visualizing all potential environmental product options embodied in the term 'Design for Environment'. Before it was put to use in this study, the DFE strategy wheel had previously been used by a variety of people (students, entrepreneurs, environmental experts) in various settings and with various targets. For example, it was used in several product development projects in the years 1993 to 1997. Among these projects were about ten students' graduate projects that had been carried out in industry (e.g. Luiten, 1994; Overschie, 1994; Van Zuijlen, 1995; Visser, 1996; Ridder, 1996; Hoogendoorn, 1997). An abstract version of the DFE strategy wheel was applied in the Environmental Innovation Scan, the auditing method specially developed for the IC EcoDesign project. Furthermore, the model was discussed and tested during a one-day workshop with six DFE experts. Finally, the DFE strategy wheel was discussed thoroughly with several DFE researchers and practitioners before it was included in the UNEP EcoDesign manual (Van Hemel and Brezet, 1997).
These experiences showed that the DFE strategy wheel did indeed function as it was meant to do. However, we should point out that the structure of the DFE strategy wheel was occasionally less transparent than intended.

The limitations of the DFE strategy wheel are:

- Distinction of a product component, product structure and product system level. The eight DFE strategies are each assumed to affect one of these three levels in particular. In practice, this distinction proved to be somewhat too generalized. In spite of this, we still recommend continuation of the distinction of three levels because of the normative element. Companies should be stimulated to strive for environmental product innovations and to reconsider the product system, instead of sticking to minor environmental product modifications at product component level only.
- The DFE strategy wheel and its underlying typology of DFE strategies and principles were sufficiently transparent to allow us to typify any set of DFE improvement options. Sometimes, however, users were a little confused as to how to categorize certain improvement options. These experiences were used to improve the DFE strategy wheel. We further recommend proper instructions and exercises on how to work with this instrument for those who are new to it.
- It was not always clear how to draw the area in the middle of the wheel; should it be as large or as small as possible? Because this area is intended to visualize a company's DFE ambitions at the start of a specific DFE project, the aim should be to make the area as large as possible. The problem was solved by adding the symbols (+) and (-) to the model, and by colour-coding the area that represents the DFE ambition as 'Priorities for the new product'.

Erroneous expectations

Users of the DFE strategy wheel are sometimes inclined to perceive it as a decision support tool (Hanssen, 1997). The model tends to make them think that DFE priorities can be set only if the DFE strategy wheel is used. This is not the intention of the model. It is intended to be complementary to existing DFE tools for life cycle analysis. The DFE strategy model as such does not help the product developer to identify *what are* the most urgent environmental problems of his product, but provides him with ideas on *how to solve* the product's identified environmental problems. To learn what are the most urgent environmental problems related to a product a life cycle analysis is required, a quantitative life cycle assessment for instance (e.g. as described by SETAC, 1993; UNEP, 1995) or a more qualitative technique like the MET matrix (Brezet et al., 1994). As described in detail in the UNEP Ecodesign manual (Van Hemel and Brezet, 1997) setting DFE priorities means finding the balance between entrepreneurial and environmental requirements regarding the new product system. Only after the DFE priorities become known can the DFE strategy wheel serve to visualize the DFE ambitions of a specific project. This 'misinterpretation' problem can only be solved by providing the model with an explanation of its intended function in the product development process.

Future application of the DFE strategy wheel

We recommend use of the DFE strategy wheel (or the underlying typology of DFE strategies and principles) in future projects to boost the utilization DFE in industry as well as in future research on DFE implementation. As we experienced in this study too, there is a need for a 'common language' in the field of DFE to enable comparison of DFE initiatives taken in industry. The study reported in this thesis has proven that the DFE strategy wheel can serve as this common language. All 596 DFE improvement options suggested to the companies that took part in the study could be typified by means of the DFE strategy wheel. Moreover, Chapter 2 showed that other typologies described in literature fit in well with the typology of DFE strategies and principles presented in this thesis.
We do not recommend elaboration of the DFE strategy wheel as such into a quantitative decision-support tool, competing with methods like life cycle assessment (LCA) or life cycle costing (LCC). This would make the model too 'sophisticated' and lower its present level of functionality and ease-of-use. We think the DFE strategy wheel functions best if it complements, not competes, with other tools for Design for Environment.

8.4.2 The method for measuring DFE performance

Chapter 3 described the method for measuring the results of the IC EcoDesign project in companies that had participated in 1995. It was argued that the most suitable method was an activity-based or process-based approach: measuring the extent of change in the direction of DFE in a company. The companies' DFE performance was specified according to three dependent variables: DFE focus, DFE result and DFE learning. Each of these variables was measured by a subset of indicators; combined, they draw a qualitative as well as a quantitative picture of a company's DFE performance. Chapter 5 presented the actual results of this measurement. This section reflects on the method for measuring the DFE performance of a company as used in this study.

Measuring the added value of the IC EcoDesign project

Common to research which studies the results of intervention in organizations, it is difficult to know whether the results recorded are indeed the result of the intervention in question. Some events that do not, or only indirectly relate to the IC EcoDesign project may have influenced the DFE performance of the participating companies. With regard to measuring a company's DFE result in terms of the actual environmental improvements to the product, packaging or process, this problem was tackled by asking to what extent the specific DFE improvement option (suggested by the IC consultant) was new to the company. Because the indicators for DFE learning proved to be less tangible, the problem was more difficult to tackle with regard to measuring a company's DFE learning in terms of the extent to which a company will be able to use DFE on its products independently in future projects. The questions that were used for the purpose of identifying a company's DFE learning prompted the respondents to focus on the added value that had been achieved by the IC EcoDesign project for the aspect of DFE learning. However, the extent to which DFE learning had been boosted by the project and not by other factors could not be quantified; we had to rely on the respondent's perception.
A scientifically correct method would have been to perform two measurements, one before and one after the EcoDesign intervention. However, due to the settings of the research project in relation to the IC EcoDesign project a so called zero-measurement was out of the question. In future research, we recommend a proper 'zero-measurement' before the intervention takes place in connection with both the company's DFE result and its DFE learning.

Asking for opinions leads to subjectivity

Another point requiring attention is that, as was the case regarding the added value of the project discussed above, the inventory of the extent to which the suggested DFE improvement options were realized is also subjective. First of all we must rely on the answers of the company's representatives. Their answers could suffer from 'window dressing'; the interviewee responding in a somewhat more positive way in order to make out that the company's DFE performance is better than it in actual fact is. Or it could be that he did not want to disappoint the interviewer, the IC EcoDesign project coordinators or the IC consultant involved. As an alternative approach, the researcher could be more actively involved in the process of change in the companies studied. This, however, would imply that only a small group of companies could be compared.
Secondly, the opinions of the companies' representatives on the realization of the 596 DFE improvement options were 'translated' into success rates. This rating of all 596 DFE improvement options was performed by one person alone, the researcher. Nevertheless, it might also have been responsible for introducing a certain amount of subjectivity.

DFE focus

The typology of DFE strategies and principles, introduced in Chapter 2, presented the opportunity to typify all 596 suggested DFE improvement options. This made it possible to identify the DFE focus of each company and obtain an insight into the strategic choices concerning DFE made by the companies. A company's DFE focus includes all DFE improvement options prioritized by a company (attributed a success rate 4, 5 or 6). A cluster analysis was carried out to cluster the companies into eight DFE focus clusters, based on the number and type of DFE principle of the specific DFE improvement options that had been prioritized. This clustering could be used to reflect upon hypothesis 2.
However, there were two reasons that made further statistical analysis impossible. First, DFE focus is a nominal variable. Second, the 77 companies studied in this thesis formed a very heterogeneous group. They differed not only in size (though each of them belonged to the group of small and medium-sized enterprises with less than 200 employees), but in type of product as well. As many as ten different branches of industry were represented. As a consequence of this heterogeneity and the limited number of cases, statistical analyses for the purpose of comparing and explaining the DFE foci of the participating companies were meaningless. This combination of heterogeneity and limited number of cases was consequently a drawback in this study. Future comparative research would be better to focus on one to three branches of industry at a time, in order to achieve conclusions which are more reliable than indicative.

DFE result

Within the limitations of the present research setting the activity-based method for measuring DFE result used seemed to be most suitable. It helped us to distinguish companies with a high DFE result from those with lower results. However, we acknowledge that this measuring method does not directly reveal the actual environmental improvement of the product in environmental, quantitative terms. A more reliable method would have been to consider the specific environmental benefits of all DFE improvement options by performing life cycle assessments (LCA). However, in the settings of the present study and the IC EcoDesign project it was not possible to measure the quantitative long-term environmental effects of the IC EcoDesign project. Three important reasons why an environmental product analysis was not performed are 1) that the product redesigns had not always already been implemented, 2) that making a quantitative life cycle assessment would have taken more time than we had available, and 3) that it would have been very difficult to motivate the companies to gather and hand over all necessary quantitative environmental product life cycle information.

A 'bypass' therefore had to be created. This bypass for measuring a company's DFE result is an assessment of the state of realization of DFE-related measurements (referred to as an activity-based approach (Jakobs and Cramer, 1995)). The aim of this measurement is to find out how much the project had advanced a process of change in the direction of DFE in a specific company. The assumption here is that each suggested DFE improvement option has its own specific environmental benefit. The more DFE improvement options a company has realized, the more eco-efficient will the redesigned product be.

Some risks of the activity-based approach are described by Dieleman (1991) and Van Berkel (1996:42). They condemn simply counting the number of improvement options given that this reveals nothing about their relative importance in terms of innovational potential or environmental benefit. Consequently, the present study assessed not only the number of suggested DFE improvement options, but also the extent to which each option has been realized *and* the newness of each option. In the formula for calculating a company's DFE score, the average success rate of the options dominates the number of options. Moreover, two separate indicators for estimating the innovational potential of the set of DFE improvement options for each company were included: the DFE design impact and DFE result opinion. This made the activity-based approach suitable for measuring the companies' DFE result in this study, regardless of the limitations mentioned above.

In this study the companies' DFE result was measured with a twofold aim. First, we wanted to find out how much added value had been produced by the IC EcoDesign project. The most important indicators for this are the DFE project score, DFE design impact and DFE result opinion. Second, we wanted to know what characterized the companies that are very active and those that are inactive in terms of DFE. The most important indicator then is the DFE score. Whether this score was the result of the IC project or not was an issue of less importance. Due to this twofold aim, all four DFE result indicators were applied.
For future research on DFE implementation we recommend focusing on only one of these two questions because each needs a specific research design. For future research on the results of DFE intervention programmes (like follow-up research on the results of the IC EcoDesign project) we recommend using the same indicators. If time is limited we recommend working with only three DFE result indicators: DFE project score, DFE design impact and DFE result opinion. In combination, they give a good idea of the added value produced by the IC EcoDesign project and the extent to which the products, packaging and processes involved were actually redesigned. The DFE score is of less value since it does not reveal the added value of the intervention project.
In future research an attempt might be made to assess the result of the IC EcoDesign project in terms of actual environmental benefits. A precondition here would be that the measurement is made about three years after the DFE interventions. Only then will the exact product redesign and the extent to which it substitutes other, less eco-efficient products be known. Yet there is another condition that must also be met: companies must both be prepared and willing to provide all quantitative, environmental information necessary for performing life cycle assessments.

For future explanatory research on the DFE behaviour of companies we recommend not to link up with an intervention programme, but to independently select the group of companies to be studied. We would suggest studying the DFE behaviour of companies in specific branches of industry, preferably competitors. In a second stage, the research could become cross-sectional, comparing DFE behaviour among different branches of industry. For this type of research the DFE result indicators used in this study would be less suitable. We recommend setting up a branch-specific list of the most relevant DFE principles, and assessing what the companies studied have done to implement these potential DFE improvements. The nine 'success rates' used in this study could be applied for this purpose. If the companies are competitors we can estimate the environmental benefit of the DFE improvements discussed. To do this, a weighing system could be developed to distinguish DFE improvements which have a high environmental benefit from the less promising improvements. Using the DFE typology, the nine success rates and the sector-specific weighing system then gives us a good impression of the type and number of DFE efforts in comparable companies.

DFE learning

Especially when measuring this type of project result it was difficult to isolate the DFE learning (initiated by the IC EcoDesign project) from the DFE learning the company had already initiated. Another issue was the high level of researcher expectations in connection with DFE learning. The questions in the questionnaire had therefore been worked out in detail: the questionnaire contained a total of 47 questions related to DFE learning. As a result, the empirical findings were somewhat 'superficial'. For instance, we now know that 17 companies drew up a DFE checklist to use in product development. However, we can only guess what these checklists look like and how they are actually used. A future, more in-depth study could provide additional insight into the character and reach of organizational changes (like type, comprehensiveness and utilization of DFE checklists) embodied in the expression 'DFE learning'.

These 47 variables were combined to form only nine indicators for DFE learning which could not be predicted. Subsequently, four indicators for DFE learning were selected, based on their explanatory value, the number of companies the indicators included, and their discriminatory value (the variance should be sufficiently high). Cronbach's α, as well as a Principal Component factor analysis, proved that the four indicators could be combined into a single scale referred to as the DFE learning scale. This scale was used in combination with the four selected indicators for DFE learning to achieve a better interpretation of the research results. We must admit that by reducing the data to this extent a certain amount of information was lost. Nevertheless, the method for measuring the DFE learning in the companies worked sufficiently: it enabled us to distinguish the companies manifesting a low level of DFE learning from those with a moderate or high level of DFE learning. However, we strongly recommend performing a zero-measurement in future research on the implementation of DFE in industry.

Furthermore, we recommend working only with DFE learning indicators which lead to discriminating empirical data in the sense that they clearly distinguish companies with a high DFE learning from those with a lower DFE learning. Indicators in which *all* SMEs score badly should therefore be put aside. The following DFE learning indicators yielded relatively high scores and are therefore preferred:
- DFE objectives (integrating DFE in in-house product planning procedures);
- DFE management system integration (especially linking DFE to existing EMS or QS);
- DFE internal involvement (involvement of management and product developers);
- DFE awareness (increase of DFE related knowledge);
- DFE follow-up activities (especially regarding application of DFE experience to other products);
- DFE protocol (especially in terms of using a DFE checklist).

For statistical analyses the DFE objectives and DFE awareness indicators are most useful, since they are not dichotomous but have a five-point scale.

8.4.3 Linking up with the IC EcoDesign project

The IC EcoDesign project offered a good opportunity for an initial, explorative study on how small companies cope with the subject of Design for Environment. As a result, the study depended strongly on the settings of the IC EcoDesign project, like its planning, the number and type of companies included and the intervention methodology. The researcher had the opportunity to influence the intervention methodology to a certain extent. The DFE strategy wheel was introduced to typify the DFE improvement options suggested by the IC consultants. Furthermore, the researcher was asked to develop an instrument which could be used to monitor the environmental and commercial results of the project, a year after its start. During the monitoring process, it was possible to gather additional data for the specific research questions of this thesis. These were all reasons why we linked up with the IC EcoDesign project. However, this decision also had its limitations. These are described below.
- One negative consequence of the research setting was that the planning of the IC EcoDesign project was imposed on the research planning. The result of this was that the research hypotheses had not yet been formulated in detail by the time the empirical data had to be gathered. For future research we recommend the development of a more specific theoretical framework in order to gather empirical data in a more selective, i.e. more efficient, way.
- The settings of the research project in relation to the IC EcoDesign project made it impossible to perform a so called 'zero-measurement' in the companies. This was a drawback, especially when measuring the companies' additional DFE learning.
- Another consequence of our linking up with the IC EcoDesign project was the number and types of companies included in the study (these could not be influenced by the researcher). This particularly obstructed our understanding of why companies share a certain focus regarding DFE. As assumed, we found that companies could be grouped into specific DFE focus clusters, based on similarities in DFE focus. Furthermore, the findings indicated that companies in a certain DFE focus cluster also had a comparable DFE result and DFE learning. Due to the limited number of data these conclusions could not be elaborated in even greater detail. To enable further research on this topic

the clusters identified should be much more homogeneous than they were in this research. Therefore, in future research on DFE implementation we suggest limiting the scope to a small number of branches of industry.

Notwithstanding these limitations, the IC EcoDesign project offered, and will continue to offer a good opportunity to study the DFE behaviour of SMEs. Therefore, we recommend the monitoring of the SMEs participating in the project in the years 1996 to 1998 as well. This will increase the number of participating companies and thus the reliability of the research findings. We also recommend following the companies studied in this thesis over the coming years. Longitudinal research should help us measure and explain how the DFE performance of these companies develops over time.

8.4.4 Research methodology

Confrontation with Gladwin's criticism

Gladwin listed ten limitations of the currently used research methodology in environmental management research (Gladwin, 1993:43). These can be summarized by the following quotation: 'Many researchers have apparently assumed that greening is so embryonic, so different, so special, that work of a largely exploratory and pre-theoretical nature is fully appropriate. [...] If our work is to have greater impact, then it must become more theory-driven.' (Gladwin, 1993:44).

Can we now state that our study met the three core criteria of the scientific method as quoted by Gladwin (1993:43): 1) adequate description and classification, 2) generalizability of findings, and 3) predictability of conclusions? No; we must admit that we only partly met these three criteria.
We feel that this study sufficiently met the first criterion 'adequate description and classification' by means of the DFE strategy typology and by using clear definitions of all the terminology used in the study. We are less sure regarding the other two criteria. A clear research model and a set of six hypotheses formed the underlying structure for this study. This structure helped us to organize and reflect upon the empirical findings. However, these findings are only to a limited extent generalizable: they only count for a group of 77 small and medium-sized enterprises that participated in the Dutch IC EcoDesign project. Furthermore, by means of statistical analyses we tried to explain why certain DFE principles were more successful than others and why certain companies have a higher DFE performance than others. The explanations found do not go beyond being 'indications', mainly because we only used bivariate statistical analyses and did not assess the causality of the relationships found.

Despite these shortcomings, we think that this study has provided us with valuable new insights into how SMEs cope with the subject of DFE. We performed empirical, comparative, explanatory research. We used precise definitions. We used a research methodology consisting of a clear research model, underpinned by empirically testable propositions, and well-described measuring instruments. The research model and hypotheses were constructed by means of the research findings of other scholars in order to compare and cumulate research findings. Gladwin stated that these characteristics are lacking in most environmental management research. However, future study on this subject could still be improved. Therefore, the following lists a set of suggestions for improvement of the research methodology applied, in order to make findings of future research on the subject of DFE even more generalizable, predictable and theory-driven.

Two separate research questions, A and B

A striking characteristic of the research model, structuring the study reported in this thesis, is that it distinguishes two separate research foci, A and B. Why did we not integrate these separate foci into a single, overall research model or just consider one of them? Research focus A was the question why certain DFE principles were more successful than others. Research focus B specified the question why certain companies were more successful in DFE than others. Had it been our aim to relate research focus A to research focus B, a third research focus C would have been the result: to study whether, and why, certain companies prioritized a common set of DFE principles. However, due to the specific research setting (a small number of very heterogeneous companies) and the limited time available, only an initial effort went into studying this research focus C.

We therefore recommend the elaboration of research focus C in future research. The resulting research question, specifying this focus, would be: Do companies with a similar DFE performance prioritize similar DFE principles, and if so, how can this be explained? Valuable additional insight can be gained if we study to what extent a company's strategic DFE choices - in terms of number and type of DFE principles prioritized - can be explained by company, product, respondent or intervention characteristics.

Furthermore, to make the research less complex we could have selected just one of the two research questions. Because this would have left a large amount of interesting research findings unpublished, it was decided to report on research question A *and* B in this thesis. The positive consequence of these two research foci is that a large amount of empirical data was gathered, exploring the two questions. Nevertheless, a negative consequence was that, since the two research questions were so different, two studies were in fact performed simultaneously. Both questions were answered in less detail than initially foreseen. This was worsened by the fact that little theory was provided in environmental management literature to form a proper theoretical framework for the two studies. A recommendation for further study on this subject would be to uncouple the two subjects and provide each of them with a strongly focused theoretical framework and an individual research setting that best suits the specific subject. Theoretical perspectives could be derived from strategic management and organization theory.

The relative importance of stimuli and barriers

An example of the above limitation is the following. During a telephone interview the respondents were prompted to state stimuli and barriers that played a role in deciding whether or not a certain DFE improvement option should be prioritized. Because such an interview could not take longer than one hour it was decided not to record how much influence the respondent thought each stimulus or barrier had on his DFE decision-making. Consequently, we had to assess the relative importance of stimuli and barriers in an indirect way. If only one of the two research foci had been studied, the limited time available would not have been such a practical problem. The sets of stimuli and barriers drawn up in this study can be used in future research; it is recommended that an assessment be made not only of whether the factor is relevant, but also of its relative importance.

From bivariate to multivariate analysis techniques

In order to analyze why certain companies perform better in DFE than others, an instrument was developed to measure company DFE performance. By means of bivariate correlation analyses, in Chapter 7 an assessment was made of the relation between various indicators of DFE performance and four sets of explanatory variables, clustering company, product, respondent and intervention characteristics. The results of the bivariate statistical analyses could only be interpreted as indications. In future research, the present data could be analyzed in more detail by means of multivariate statistical techniques. Would-be correlations could be discovered by means of so-called partial correlation analyses.
As an example, the study supported the assumption that the more innovative a company, the higher its DFE performance (hypothesis 3.A). However, because not all indicators for innovativeness that were used supported this hypothesis to the same extent, further multivariate analysis is suggested in order to assess the interrelations between the indicators for innovativeness, and to relate them to the companies' DFE performance.

Causality of relationships

Likewise, no effort was made to study the causality of the relationships found. As an example, the five indicators for the companies' DFE result, and the five indicators for their DFE learning showed a certain amount of correlation; this ranged from 'slightly' to 'considerably'. This means that most companies with a high DFE result also showed a relatively high DFE learning and vice versa. However, we did not assess the causality of these relations. The question as to how much a company's DFE result influences its DFE learning or vice versa is an interesting topic for follow-up research.
We recommend analysis of the present data by means of multivariate techniques and assessment of the causality of the relationships found. This will result in a better understanding of what characterizes and motivates companies with a high DFE performance.

8.4.5 Topics for future research

Because there was little literature available on the utilization of Design for Environment in (small) companies, the research was predominantly descriptive and explorative. As a result, only indicative answers to the central research questions could be given. In addition, this study gave rise to several new research questions. To further develop our knowledge on the DFE behaviour of (small) companies we recommend more of this type of study, though in a different, less explorative setting. Recommendations, based on this study, on how to proceed with research on DFE implementation in (small) companies are given below.

A Recommendations for improving the DFE strategy wheel

1. Developing heuristics for DFE

Initially, the research tended to focus on the question whether heuristics could be developed to prescribe which DFE strategies or principles are best to realize in a specific situation. The idea was that some twenty product groups could be distinguished; for each of these product groups an optimal set of DFE principles could be prescribed, considering and balancing environmental as well as entrepreneurial demands. Now, after having completed the study, this idea is considered naive and unfeasible. Certain products may have much in common, yet the companies that produce them vary to such a large extent that it would seem impossible to give them sound advice as to the best DFE principles to pursue both from the environmental and their specific entrepreneurial perspective.
What could be studied however (and this seems to be very valuable) is the question whether DFE advice can be formulated from an environmental point of view for specific product groups (see also Rombouts, 1998). In the second stage, the company itself could then decide which DFE principles to use in the short and long term, and which are the most appropriate from its own, specific entrepreneurial perspective. As a start, the results of life cycle assessments that have already been completed can be aggregated into DFE heuristics, conceived for each product group distinguished.

2. Anticipating synergy and conflicts between DFE principles

Another initial objective of the PhD research was to construct an overview of the interactions between the various DFE principles as distinguished in the DFE strategy wheel. Two or more DFE principles can interact mutually in a positive way; they then lead to synergy. However, other DFE principles are known to interact in a negative way; they are mutually conflicting. In addition, a second overview could be made, revealing the interactions between DFE principles ('environmental product requirements') and other, more traditional, product requirements.
In the study reported in this thesis attention was limited to the interaction between DFE principles on the one hand, and traditional product requirements on the other. For each DFE principle the company respondents were prompted to state the extent to which a specific DFE improvement option had been prioritized thanks to its synergy with a predefined traditional product demand (expressed as 'internal stimulus') or, conversely, had been rejected because of its conflict with a product demand (expressed as 'barriers'). Identifying and describing the synergy and conflicts between DFE principles mutually, and between DFE principles and other product demands, is still a valuable subject for future research. With this knowledge, companies and intermediary organizations are more able to tackle the problems that arise when implementing DFE.

B Recommendations to improve our understanding of DFE learning processes in companies

1. Understanding DFE learning in industry

Because of the explorative character of this study, certain issues could not be studied in depth. Especially the findings with regard to the DFE learning of the companies studied are somewhat superficial. We know that companies differ considerably in terms of DFE learning. However, the empirical findings presented do not reveal the various aspects of DFE learning (like DFE checklists, follow up activities) and how intensively they are used in corporate development practice. This issue is worth studying in more detail in future research. We agree with Gladwin (1993: 43) that existing organization theory could provide the necessary theoretical fundament. Moreover, we acknowledge the importance of strategic management theory.

Organization theory - in particular the capability theory - was used in this thesis to operationalize hypothesis 1.C. However, the empirical findings did not support this hypothesis. Doubting the validity of the capability theory would be jumping to conclusions. The mismatch between theory and our empirical findings could be due to the way the capability theory was operationalized in this study. In the process of translating elements of the capability theory into research questions, the theory may have been incorrectly interpreted. Organization theory is however believed to offer a valuable theoretical framework for studying how companies (learn to) implement DFE in their product development process. It is therefore recommended to make a more detailed assessment of the way organization theory - especially the capability theory - could be operationalized in order to support research in the field of DFE.
The study also showed that, in 1997, companies implement DFE improvement options which are associated with commercial opportunities: new market chances and, to a lesser extent, cost reduction. We recommend studying the way companies set their priorities regarding DFE in more detail and in a less explorative setting than was done in this study. In order to cumulate research findings (Gladwin, 1993:43) we suggest linking this research to existing theory on strategic management.

2. *Understanding the relationships between EMS, DFE and PEMS*

The findings of this research indicate that an EMS could be a stepping stone towards DFE, and vice versa (hypothesis 3.B). It would be interesting to study to what extent EMS and DFE enhance or oppose each other in product development practice. This question is particularly relevant since the Dutch Government has introduced a support scheme to promote the implementation of 'product-oriented environmental management system' (PEMS) in industry. The concept of PEMS is obviously related to the already familiar concept of EMS, referring to managerial procedures which focus on good housekeeping, cleaning technology and cleaner technology. Moreover, PEMS is also regarded as a follow-up to DFE. For companies that want to implement DFE, a PEMS could be an essential second step, rooting environmental issues into their product development procedures. The interrelations, synergy and conflicts between the three concepts EMS, DFE and PEMS in industry are worth studying in detail.

8.5 Recommendations for implementing DFE in small and medium-sized companies

The following section sets out recommendations on how to further enhance the implementation of DFE in industry. Although these recommendations are generated by studying DFE behaviour in SMEs, many of them are applicable to larger companies as well.

8.5.1 Recommendations for intermediary organizations

Based on the findings of this study we can state that the IC EcoDesign project approach was an effective one. Indications for this are the following findings:

- 247 (41%) of all 596 DFE improvement options suggested to the 77 SMEs interviewed were prioritized, implying that they had either been realized or would be realized within 4 ½ years of having received the EcoDesign advice. Of these 247 DFE options prioritized, 183 (74% of 247; 31% of 596) had already been implemented.
- 60 out of 77 companies studied had prioritized at least one DFE improvement option. This means that the option will be implemented within 4,5 years after it was suggested to the company.
- One-third of the DFE options prioritized was completely new for the companies involved; another one-third was familiar, but was considered thanks to the IC EcoDesign project; the SMEs had considered the last one-third of the DFE options regardless of the IC EcoDesign project.
- In 21 companies (out of 77 companies studied) the IC EcoDesign project contributed towards 'major product redesigns'.

More than once did the companies interviewed characterize the project as a 'catalyst', starting or accelerating the process of application of DFE in their company.

Despite this, the IC EcoDesign project approach could still be improved upon. This study led to the following suggestions for further improvement of the IC EcoDesign project. Of course, these suggestions are valuable for other intermediary organizations as well.

Careful selection and proper training of consultants

This study has made it clear that the role and influence of the consultants with respect to DFE is very important. Whether this depends, for instance, on the consultant's knowledge, his or her consulting style or attitude towards the subject of DFE is not clear. A point for future concern and, preferably, research is how this influence can be explained and what characterizes those IC consultants who arouse significant DFE performance. This could help intermediaries in selecting and training the best prepared consultants to motivate companies to use DFE in product development. Preference is given to such consultants for performing DFE interventions. They could also encourage other consultants by passing on their knowledge or enthusiasm during training sessions. Furthermore, consultant DFE training could be optimized so that the consultant better matches the 'ideal' DFE consultant profile.

Careful selection of companies

We recommend intermediary organizations like the Innovation Centre Network to be more selective when choosing the companies for participation in a project like the IC EcoDesign project. This study showed that major barriers for DFE arise if companies do not feel responsibility for realizing the suggested DFE options or if companies wait for technological solutions (alternatives to existing environmental problems) to be developed by other companies in the product supply chain. In order to be successful, the participating companies should be both willing and able to apply DFE to their products. With respect to wholesalers or 'jobbers' the effect of the DFE approach will be limited. Companies that regard product development as their core activity and have high innovational ambitions at the moment of intervention are to be preferred.

Enhancing the product supply chain approach

According to this study, a very influential barrier towards DFE arises if companies do not feel responsible for implementing a certain DFE improvement option. Another influential barrier arises if a company has no technological alternative solutions for an environmental problem and is unable or reluctant to develop that technology themselves. If one of these barriers exist, the DFE process comes to a halt. To prevent this we suggest that intermediaries should focus their attention on product supply chains as well as on individual companies. If a product supply chain is considered as a whole, it is possible to 'redistribute' DFE responsibilities to companies which are, and indeed feel they are, responsible.

Suggesting convincing DFE improvement options

A very influential barrier standing in the way of realizing a DFE option arises if a company doubts the environmental benefit of the suggested DFE option. We recommend consultants to be critical about the actual environmental benefit of the DFE improvement options they suggest in DFE action plans. Moreover, the consultants should make sure that the company is convinced of the environmental benefit of the DFE options included in the company's DFE action plan.

Promoting benchmarking

The activities of competitors were apparently very strong external stimuli, even though they were not mentioned frequently. If a competitor had realized a certain DFE improvement, then the company studied was inclined to implement it as well. It could therefore be worthwhile confronting SMEs more directly with the DFE initiatives of their competitors - if any - by means of environmental benchmarking.

Providing extensive follow-up support

A rough indication of the companies' appreciation is their willingness to cooperate in the monitoring research. Almost all companies consented to cooperate. Some of them even said that they very much appreciated this follow up. In a dozen cases the monitoring research led to requests for additional support. The researcher passed these requests onto the IC consultant involved. This experience leads to the conclusion that follow-up is important and that the IC EcoDesign project approach could be improved upon by ensuring more extensive follow-up support of the IC consultant involved.

8.5.2 Recommendations for small and medium-sized enterprises

Based upon this study we have the following recommendations for small and medium-sized enterprises that want to start implementing ecodesign.

Start an ecodesign pilot project

A good way to start taking environmental issues into consideration in product development is to start up an in-house ecodesign pilot project. A project of this kind is best if it is focused on a product the company would like to redesign anyway. Such an ecodesign pilot project helps the company to identify those ecodesign principles that are the most relevant for the company's own specific situation. It can then start to search for specific (environmental) information, set realizable and measurable ecodesign priorities, and designate ecodesign responsibilities. As this study has shown, ecodesign can serve as a stimulus to re-think a product's design; it can also lead to a variety of additional advantages. This opportunity should not be missed.

Ask for assistance

SMEs are recommended to link up with existing ecodesign support programmes. An SME can decide to apply ecodesign without any external assistance. For instance an ecodesign do-it-yourself manual could be used (e.g. EPA, 1993 or Van Hemel and Brezet, 1997). However, since SMEs are known to be kept busy dealing with their day-to-day business affairs, we recommend that they ask for external assistance (which is readily available these days). Assistance can be obtained from intermediary organizations (like regional innovation centres or industrial sector organizations), universities, trade unions, government organizations and even from other companies in the product supply chain, e.g. suppliers.

Incorporation of DFE

The advice after a company has applied ecodesign principles in a pilot project is to proceed with incorporating ecodesign in its development procedures. Among other things it should evaluate the extent to which it has realized its ecodesign targets, and why. If the company in question had received external support, it should ensure proper follow-up support. The company is then advised to set its ecodesign targets for the coming three years. To ensure the incorporation of ecodesign, the ecodesign tasks could be integrated in existing development procedures, for example by means of an ecodesign checklist.

Aim for environmental policy

We recommend that a company decides on the actions to take on environmental issues for all company functions at the same time in order to have a complete point of reference for the coming years. We also recommend the development of some sort of environmental policy in which their environmental concerns are expressed and translated into concrete targets for environmental management, for cleaner production and for ecodesign. Working with the ISO 14.001 structure could offer an appropriate framework for that, even if a company is not aiming for ISO 14.001 certification of their environmental management system.

Join forces horizontally as well as vertically

SMEs in particular could benefit from cooperating with other companies. Horizontal cooperation (cooperation with other firms in the same branch of industry) might convince suppliers to develop more eco-efficient technologies or materials. Horizontal cooperation also enables common ecodesign target-setting (at branch of industry level); this is necessary for communication with governmental legislative bodies.
Vertical cooperation (cooperation with companies in the same product supply chain) is also recommended. Vertical cooperation helps to (re)designate ecodesign responsibilities to those partners in the product supply chain who really are - and feel - responsible for a specific ecodesign task.

.5.3 Recommendations for industrial designers

Another set of recommendations is given below. It lists recommendations for industrial designers or product developers who want to apply ecodesign in their product development practice.

Start with the most appealing DFE principles

This study has shown quite clearly that ten of the 33 DFE principles are the most successful. We recommend that an industrial designer who wants to apply ecodesign should start by considering these ten DFE principles, assuming they are relevant. By doing this he will raise the company's enthusiasm for ecodesign. The ten most successful DFE principles are recycling of materials, high product reliability/durability, use of recycled materials, low energy consumption during use, product remanufacturing/refurbishing, less production waste, clean production techniques, reduction in product weight, use of clean materials and less/clean/reusable packaging.

Get the commitment of top management

This study indicates that an ecodesign project has the highest chance of success if the SME's owner-manager was directly involved. In other words: an industrial designer should ensure the commitment of top management if he intends to apply ecodesign in a certain development process. In collaboration with the management he should then go about setting ecodesign priorities. The management's commitment is essential given that ecodesign demands extra attention, time and, consequently, resources.

Speak the company's language

In order to convince decision-makers of a certain DFE improvement option, as well as to give them the arguments to convince others, the industrial designer is advised to set out the option's improvement potential on the basis of 'facts and figures'. The environmental benefit might be expressed as a reduction of environmental costs (for instance by means of an Eco-Indicator) or as a reduction of costs in financial terms. Deliberately consider and communicate the additional advantages which complement a specific DFE improvement option.

Use stimuli, discuss barriers

This study showed which are the most influential stimuli and barriers for DFE. The designer is recommended to analyse which stimuli or barriers could influence his specific ecodesign proposal. Are customers expressing environmental concerns? Is the product subject to any environmental legislation, or will this be the case in the future? Are there any branch of industry initiatives? Are suppliers developing new eco-efficient materials or technologies? Are competitors entering the market with green claims?

In addition to these influential external stimuli, the company's interest could be raised by means of internal stimuli. Does the proposed DFE option imply any innovational opportunities? Does it lead to an increase in product quality? Could it raise new market opportunities?

The designer should also be aware of potential 'no-go' barriers. He is advised to concentrate on a different DFE issue if the company does not feel responsible for implementing a certain option, if it is not convinced of its environmental merits, or if alternative technical solutions are not available.

Investigate and stimulate suppliers' developments

In the above, SMEs were recommended to ask for external assistance for ecodesign. It goes without saying that this also counts for industrial designers. This is a group that could particularly benefit from the knowledge among suppliers. Particularly SMEs are unable to invest in all potentially interesting new technologies. In order to survive, these companies must set clear priorities. The development of new technologies is therefore often left up to the SME's suppliers. We would recommend designers to investigate whether the company's (future) suppliers are developing eco-efficient technologies or materials, or whether they can motivate suppliers to do so.

Apply DFE benchmarking

Designers should not only investigate the suppliers' new developments, but the ecodesign initiatives of competitors as well. This investigation can be regarded as DFE benchmarking. If competitors claim that their products are more eco-efficient, the company is warned. If the competitors lag behind, the company could create a unique selling point.

Become a member of O2

We recommend industrial designers, especially Dutch designers, to become members of O2 Nederland. This is an organization that takes many initiatives (workshops, lectures, publication of O2 Magazine) in order to raise the awareness and knowledge of designers, product managers, researchers and environmental experts with respect to ecodesign, and to establish a network of people who use ecodesign in their profession (tel. +.31.10.411 81 02).

8.5.4 Policy recommendations

Some recommendations are set out in the following, most of which are based on the study reported in this thesis. They are primarily intended for the developers of policy for promoting DFE in industry. They include some recommendations for other external parties as well.

Proceeding with demonstration projects

First of all, government should proceed to stimulate DFE demonstration projects like the IC EcoDesign project studied in this thesis and the preceding PROMISE project. This study showed that the approach used in the IC EcoDesign project is very effective in the sense that it actually raised awareness and boosted activities connected with DFE among SMEs. Demonstration projects offer companies the opportunity to become familiar with DFE and to take some initial DFE-related initiatives. This means that companies are helped to develop an environmental product policy which they can further elaborate and implement individually after the DFE intervention. Should they still find this too complex they know where they can find additional support.

Proceeding with financial support schemes

Demonstration projects like the IC EcoDesign project help companies to familiarize themselves with the subject of DFE and encourages them to improve their products in the environmental sense. This implies that a company has to invest in new product development or product improvement, something which is often regarded as a considerable risk. Financial support schemes are effective instruments to lower the threshold for SMEs to invest in DFE after the DFE intervention. There are various financial support schemes in existence in the Netherlands. However, SMEs sometimes find it difficult to apply for these schemes, probably because of the related time schedules and necessary administration. We therefore recommend that these schemes should be adjusted to bring them more into line with day-to-day practice in SMEs.

Promoting the commercial opportunities related to DFE

This study showed that DFE was successful, especially in companies which see DFE as a commercial opportunity, as an initial investment which will be recovered in due course, as an opportunity to increase efficiency, as a means to reduce production or transport costs, or as a means to increase market shares or enter new markets. Furthermore, the study showed that a DFE option had a high chance of being realized if it produced innovational opportunities, an increase in product quality or new market opportunities. In conclusion, DFE obviously has commercial opportunities, especially for end products like those studied for this thesis. Spreading this idea is a good way of stimulating other companies to apply DFE. The Innovation Centre Network disseminates the results of the IC EcoDesign project by means of personal advice, public meetings and ecodesign case descriptions. This too is regarded as a good approach. However, the ICs are not able to reach all Dutch SMEs without further support. In addition to the promotional activities of the Innovation Centres, government should ensure the promotion of ecodesign at national level.

Providing strong and consistent external stimuli

The study shows that the SMEs studied implement mainly those DFE options that generate commercial benefit. How to motivate companies to realize DFE options with a larger environmental benefit, but which have less interesting commercial opportunities? The empirical findings imply that if we wish to boost the application of DFE in SMEs, we could increase the amount of external pressure.

The ***market pull*** could be given a boost in order to increase the amount of external pressure. We have the following suggestions:

- Individual customers and customer organizations could be provided with comprehensible information and be encouraged to ask questions about the environmental aspects of products.
- To increase the market pull for eco-efficient products, governments could oblige government and government-related institutions to buy eco-efficient products. By doing this they would boost the integration of environmental aspects in their own procurement policy and that of other large institutions like universities and hospitals.
- We also recommend proceeding with the Dutch, and especially the European energy labeling and ecolabeling schemes. The study showed that companies tend to have doubts as to whether their end users appreciate their DFE initiatives. Energy and ecolabeling schemes could have a positive influence on consumer awareness and appreciation of more eco-efficient products.
- Governments have various financial instruments like 'tax differentiation' that could stimulate the demand for more eco-efficient products and services. Governments could strive to integrate environmental costs into the traditional products' sales price. In that respect, a negative example is that Dutch government recently increased VAT for shoe repair services from 6% to 17,5%. We strongly recommend Dutch government to reduce taxes on eco-efficient services and products.

European consumer organizations like the Dutch *ConsumentenBond* regularly devote attention to the environmental profile of the products they test. In their documentation they include the results of 'DFE benchmarking'. This is read by consumers as well as producers. Because this ***eco-benchmarking by consumers' organizations*** seems to have a particular influence on the DFE behaviour of manufacturers, we strongly recommend consumer organizations to continue these benchmark tests. Government could support these institutes in the form of additional financial or informational support.

While it is more or less non-existent at this moment, ***government task-setting*** is believed to offer important external drivers towards DFE as well, especially for companies that just 'wait and see'. Government task-setting in connection with DFE (e.g. the Dutch system of environmental covenants) could have a direct influence on the environmental initiatives of SMEs, or an indirect influence by promoting DFE application in larger companies which in turn will pass their DFE demands onto their SME suppliers. As stated by Ashford (1994): 'Regulatory stringency is the most important factor influencing technological innovation'. Regulations, as well as non-regulative common standards, imply the same rules of play for all companies in a specific branch of industry. Only then will companies feel sufficiently motivated and confident to invest time and money in preparing themselves for this new situation. For instance, the impending take-back regulation in the Netherlands is seen as an initial step in this direction.

How should we motivate industry to promote the implementation of DFE? The empirical findings of this study showed that while ***branch of industry initiatives*** were scarce they were still very influential external stimuli for DFE. Many DFE options for which this stimulus was mentioned were realized. This implies that companies - especially SMEs - organize themselves best in industrial sectors, so they can set up DFE initiatives and tasks that apply to the sector as a whole. In doing so, companies stimulate each other; free-riding is prohibited.

Finally, we recommend that ***environmental organizations,*** as well as ***financial institutions,*** should act as external drivers for DFE. None of the companies studied in this thesis felt motivated by environmental organizations in any way whatever to implement DFE. Therefore, we recommend the environmental organizations to take initiatives to promote the production and consumption of more eco-efficient products. One suggestion is to cooperate with consumer organizations since they are well aware of how to communicate with individual consumers. Financial institutions can raise interest among both private and commercial investors for so-called 'green investment funds'. By doing this they offer their support to companies which are proactive towards DFE.

Applying a sector-specific approach

The study showed that certain branches of industry (the electronics industry and the machine industry) were far more positive towards DFE than others. Furthermore, the industrial sector initiatives have proven themselves to be an influential stimulus towards DFE. This forces us to conclude that in the process of promoting DFE a sector-oriented approach is recommended. Governments can reach small and medium-sized companies by adopting a sector-specific approach. Moreover, small companies belonging to a specific branch of industry could cooperate to such an extent that they could become powerful enough to interact with government institutions. This interaction could then be used to achieve environmental regulations which both consider and balance the environmental *and* the entrepreneurial concerns. As argued by Dankbaar (1996:9) only by building relationships and by introducing common values and playing-rules can companies survive the turbulent circumstances of the nineties.

Boosting product-oriented EMS

In 1997 the Dutch Government launched a scheme to promote the establishment of 'product-oriented environmental management systems' (PEMS) in Dutch industry (in Dutch: *Productgerichte Milieuzorg* or PMZ). This PEMS scheme encourages companies that already use DFE incidentally to safeguard the implementation of DFE in future development projects by means of improved management procedures. In terms of this study, the PEMS scheme boosts the companies' DFE learning. The findings of this study support this policy since they showed that companies active in the field of DFE had often already established a (partial) EMS. Furthermore, these companies were inclined to establish a link between their EMS and DFE initiatives. In conclusion, companies organizing their environmental initiatives by means of an EMS will probably also support the idea of organizing and rooting their DFE initiatives by means of a PEMS. Some companies indicated that they would like to see the introduction of a certificate which would demonstrate their DFE efforts. A PEMS scheme could fulfill this need for a formal DFE certificate. However, we must keep in mind that SMEs are not fond of certification schemes. We therefore recommend to 'down-scale' PEMS into a partial or informal PEMS that meets the particular requirements of the SME sector. The Innovation Centres could take a leading role in the implementation of such SME-specific PEMS in industry.

From ecoredesign to ecodesign

So far, the companies studied revealed DFE results that can be typified as 'ecoredesigns' or 'incremental green designs', defined as tackling one or two specific, often high profile, environmental problems (Ryan et al., 1992). By means of stronger external stimuli, companies could be motivated towards 'systematic ecodesigns' by considering and balancing all the areas of adverse environmental impact throughout its life cycle, or even towards 'sustainable product development', in which the function of the product is considered and the alternative environmentally sustainable means for providing it are examined (Dewberry and Goggin, 1996; Manzini, 1996; Smith et al., 1996). The Environmental Innovation Scan, the auditing method used in the IC EcoDesign project, was developed with the aim of stimulating awareness and giving support to SMEs when realizing 'ecoredesigns'. For the future, it would be worthwhile approaching SMEs with a programme which was more clearly focused on promoting 'ecodesigns' or 'sustainable product designs', learning from experience with the existing ecoredesign approach.

This study showed in as many as 21 companies (of the 77 companies studied) that the IC EcoDesign project had contributed towards 'major product redesigns'. This supports our idea that DFE had a major innovative potential. If companies are encouraged to implement 'sustainable product designs' they could benefit even more from this innovational potential related to design for environment.

Summary

'EcoDesign Empirically Explored; Design for environment in Dutch small and medium sized enterprises.'
PhD-thesis by Carolien G. van Hemel.
This PhD-thesis evaluates the development of cleaner products in 77 small and medium sized enterprises which participated in the EcoDesign project of the Dutch Innovation Centre Network in 1995.

A. Research setting

What was the reason for this study?

Until recently the academic literature on the environmental behaviour of industry has focused mainly on the implementation of environmental management systems (EMS), cleaning technology and cleaner technology, especially in the larger companies. Whereas the industrial community had started to focus attention on the development of 'cleaner' products, the actual development itself had hardly been subjected to any study at all in an empirical, comparative and explanatory way. Therefore, the aim of this study is to learn more about the development of cleaner products (Design for Environment or DFE) in small and medium-sized enterprises (SMEs).

The study relies on the activities carried out within the framework of the EcoDesign project of the Dutch Innovation Centre (IC) Network. The aim of IC EcoDesign project (which ran from 1995 to 1998) was to increase the level of awareness in Dutch SMEs with regard to Design for Environment. The author of this thesis was involved in developing the methodology that was used in this project and was also requested to monitor the results of the first year. The IC EcoDesign project thus offered a unique opportunity to study the DFE behaviour of a considerable group of 77 SMEs.

Research questions

The research was centered around the following two research questions:
A. *Why are certain strategies in the field of design for environment more successful than others?*
B. *Why do some SMEs perform well in design for environment while others lag behind?*

In order to assess and explain the success of the various DFE strategies, the following questions needed answering:
A.1 How should the success of the various DFE strategies be measured?
A.2 What is the variance in the success rate of the various DFE strategies?
A.3 How can the assumed variance in the success rate of the DFE strategies be explained?

In order to investigate the DFE performance of the SMEs participating in the IC EcoDesign project, the following questions were addressed:
B.1 How should the DFE performance of a participating company be measured?
B.2 What are the differences in DFE performance of the participating companies?
B.3 How can the differences in DFE performance of the participating companies be explained?

The answers to these questions could help us understand and remove existing barriers for design for environment and encourage SMEs to apply DFE in their product development.

The DFE strategy wheel

The 'DFE strategy wheel' (developed by the author of this thesis) played an important role in this study. It is based on a typology of potential 'DFE strategies' and 'DFE principles', developed to enable typification of the DFE initiatives of the companies involved in the project. The typology distinguishes 33 so-called DFE principles, possible ways to improve the environmental profile of a product system, taking all the stages of its life cycle into consideration. These 33 DFE principles are a priori clustered into 8 DFE strategies on the basis of literature analysis and current DFE experiences. The original idea behind the DFE strategy wheel was simply that it should function as a frame of reference for the researcher, giving an overview of the possible ways to improve the environmental product profile.

Later on, it also played a substantial role in the Environmental Innovation Scan, the auditing method developed by the Innovation Centre Network for the IC EcoDesign project. The DFE strategy wheel is illustrated in Figure 1.

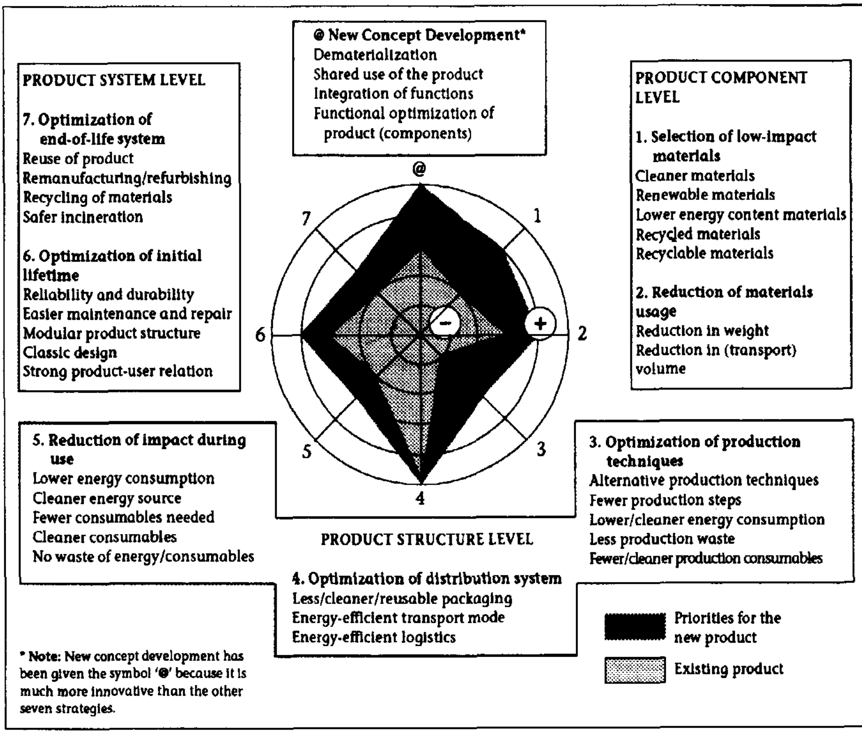


Figure 1 *The DFE strategy wheel (Van Hemel and Brezet, 1997, based upon Van Hemel, 1994)*

The IC EcoDesign project

The intention of the IC EcoDesign project was to boost awareness in SMEs regarding design for environment. A DFE intervention method was developed specifically for this project in 1994. An essential element of this method is the 'Environmental Innovation Scan' which is meant to enhance the amount of knowledge in a company on DFE and its motivation to apply DFE to one of its products. This Environmental Innovation Scan made it possible for the IC consultants to contact and discuss the subject of DFE with a large number of SMEs. The second stage of the scan offered both the company and the IC consultant involved the opportunity to go into more detail. The result of this procedure was that the companies became acquainted with DFE and the product life cycle approach without being immediately forced to make extensive Life Cycle Assessments. The outcome of the Environmental Innovation Scan was a company-specific DFE action plan, listing a set of 'DFE improvement options' suggested by the IC consultant. The number of DFE improvement options for each of the DFE action plans ranged from three to seventeen.

A total of 22 persons (IC consultants and IC assistant consultants) were responsible for carrying out the Environmental Innovation Scans in the 77 SMEs studied in this research. All 22 are employed at one of 17 regional Innovation Centres. The number of scans executed varied greatly, ranging from one to seven scans.

Participating companies

In 1995 a total of 94 SMEs participated in the IC EcoDesign project; 77 of which were included in the study reported in this thesis. The participating companies had to meet the following selection criteria: that they belonged to the SME sector (maximum of 200 employees), they were 'self-specifying' (defining the specifications for the products they produce), their products were developed in the Netherlands and that their products were physical, tangible products. Finding companies that both wanted to participate and met these criteria, was more difficult than expected.
Many branches of industry were represented; the most common were metal products, machinery and wood and furniture, followed by rubber and synthetics, electronics and the textile industry. As many as 70% of these companies employ at least one in-house product developer. Most companies are self-specifying and most companies develop end products. In general, up to the start of the project the companies had taken few environmental initiatives; 75% of the companies had no experience with design for environment.

Products involved

The products the participating companies submitted for the Environmental Innovation Scan were diverse, ranging from packaging to a coach. They differ in terms of material, production techniques and packaging, their function, type and size of market, their life time, etc.

Research methodology

The study reported in this thesis is typical of comparative, empirical, quantitative field research. It is empirical in the sense that it makes use of empirical data to assess whether a set of six hypotheses is supported or not. This data stems from 77 SMEs that participated in the IC EcoDesign project in 1995 (the 'field'). Because of this limited number of objects of study only relatively simple, bivariate statistical analyses were used. The empirical data to judge whether the hypotheses are supported by empirical evidence were gathered by two methods: a questionnaire (by mail) and an interview (by telephone).
The respondent completing the questionnaire was in all cases the person that was interviewed as well. In most cases this person was the company's owner-manager; in several of the somewhat larger companies the respondent was the head of the design department.

The thesis was based upon the two research questions mentioned above. Both research questions were elaborated into research model A and B which, together, formed the conceptual research model of the study.

Research model A

Research model A (illustrated in Figure 2) helped us to understand why certain DFE principles were more successful than others. Based on the literature on environmental management and design for environment, three groups of factors were defined which were assumed to influence the success rate of DFE principles: external stimuli, internal stimuli and barriers (both external and internal).
A total of 596 DFE improvement options were suggested by the IC consultants to the 77 SMEs as a result of the Environmental Innovation Scan. During interviews the stimuli and barriers which motivated a company to realize or reject its DFE improvement options were recorded. This revealed the stimuli and barriers for each of the 596 DFE improvement options, as perceived by the SMEs.

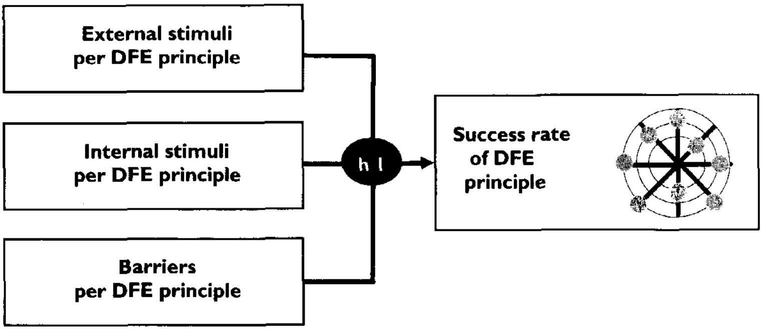


Figure 2 *Research model A with hypothesis 1 (h1), consisting of sub-hypotheses 1.A, 1.B and 1.C*

Research model B

Research model B (illustrated in Figure 3) formed the second part of the conceptual model for the research. It shows the approach we took to answer research question B on how to explain the difference in DFE performance among the participating SMEs. First, a company's DFE performance is measured through three DFE performance indicators:

- DFE focus: The choices companies make with regard to how they apply DFE to their products: which types of DFE principles do they realize, which will they reject?
- DFE result: The concrete environmental improvements of a company's product, packaging or production processes, as a result of the IC EcoDesign project.
- DFE learning: The extent to which a company has learned from the IC EcoDesign project and developed routines that enable and encourage it to apply DFE in future product development.

Second, it was assumed that a company's DFE performance depends on various aspects which include the company's specific characteristics, the product involved, the respondent and the intervention. At the moment the study was set up there was no well-defined theory that could serve as a theoretical fundament to explain the differences in DFE performance between SMEs. The present study therefore took a more explorative approach: a broad, diverging range of potential explanatory variables was selected (derived from literature), as opposed to a small, strongly focused set of variables.

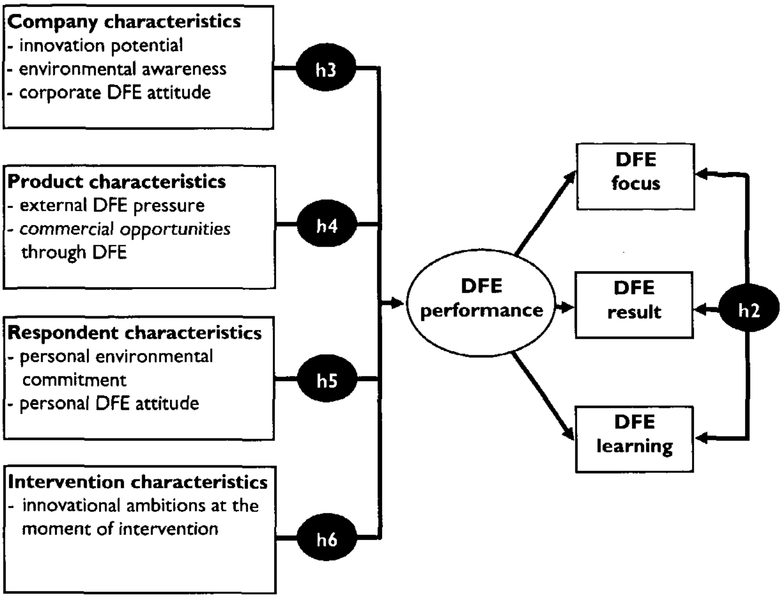


Figure 3 *Research model B with hypotheses 2 to 6 (h2 to h6), each consisting of various sub-hypotheses*

It goes without saying that there is a link between the two research foci A and B. The characteristics of the company, the product involved in the Environmental Innovation Scan, the respondent and the external and internal stimuli and barriers as perceived by the respondent are not totally independent. However, the assessment of the relationship between the stimuli and barriers per DFE principle mentioned by a specific company (research focus A) and the data on corporate characteristics and stimuli and barriers for DFE in general (research focus B) went beyond the objectives of this study.

B. Research results

Conclusions regarding the success of DFE principles

A total of 596 DFE improvement options was suggested to the 77 SMEs studied. These options were then evaluated in terms of the companies' perceived stimuli and barriers which had led to their realization or rejection. The extent to which an SME had implemented a certain DFE option was also recorded. Nine so-called 'success rates' were distinguished for this. Subsequently, the 596 DFE improvement options were clustered according to the type of DFE principle to which they belonged by means of the DFE strategy typology. This made it possible to analyze which of the 33 DFE principles distinguished had been suggested most often and which of them had had the most success.

The conclusions of the analysis reported in detail in Chapter 6 are summarized in Figure 4. This reveals the most often-mentioned, as well as the most influential external stimuli, internal stimuli and barriers.

	External stimuli	Internal stimuli	Barriers
Total number?	130	795	414
For how many of the 596 DFE options?	111 (19%)	339 (62%)	322 (54%)
Which stimuli/barriers were the most frequently mentioned?	1. Customer demands (56) 2. Government regulation (43) 3. Supplier developments (16)	1. Environmental benefit (201) 2. Cost reduction (177) 3. Image improvement (102)	1. Conflict with functional requirem. (108) 2. No distinct environmental benefit (51) 3. Commercial disadvantage (51)
Which stimuli/barriers have the most influence?	1. Customer demands 2. Government regulation 3. Branch of industry initiatives	1. Innovational opportunities 2. Increase of product quality 3. New market opportunities	1. Not perceived as responsibility 2. No distinct environmental benefit 3. No alternative solution available

Figure 4 *Overview of the number of stimuli/barriers mentioned, the number of DFE options involved, and the top three types of stimulus/barrier, according to the frequency at which they were mentioned, and their relative influence*

Figure 4 clearly shows that the SMEs studied perceived a higher number of internal stimuli than external stimuli: 795 internal stimuli were mentioned for 339 out of 596 DFE options (62%), whereas only 130 external stimuli were recorded for as few as 111 out of 596 DFE options (19%). Further study revealed that internal stimuli were not only mentioned more often than external stimuli; they also had a stronger influence on the success rates of DFE options.
Figure 5 recalls the empirical findings with regard to research question A, including the most influential stimuli and barriers, as well as the ten most successful DFE principles.

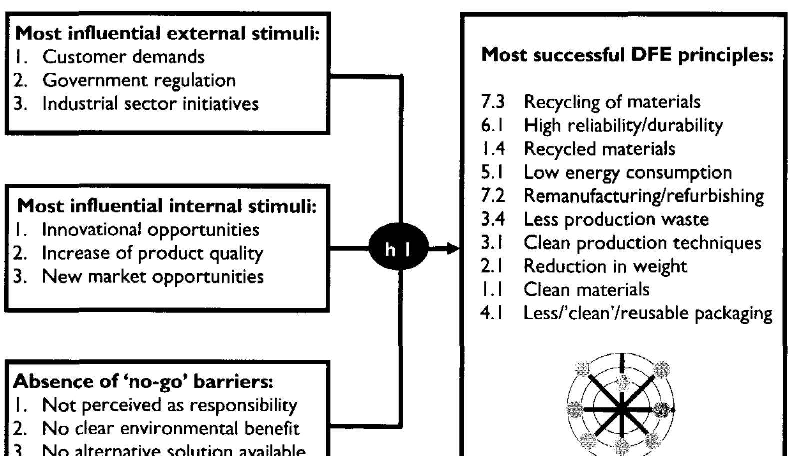


Figure 5 *The most influential stimuli and barriers, and the ten most successful DFE principles, based upon the empirical findings of this study (h1: hypothesis 1, including hypotheses 1.A, 1.B, 1.C)*

According to this study, the companies investigated gave most of their attention to end-of-life issues (recycling of materials, remanufacturing/refurbishing), to reducing product weight, and to the use of 'clean' (non-hazardous) and recycled materials. Other important topics were increasing product durability, reducing the product's energy consumption and cleaner technology (less production waste and 'clean' production techniques). Finally, product packaging was also regarded as an important environmental concern.
Figure 5 also shows that according to this study the most influential internal stimuli were the innovational opportunities of a DFE option, an expected increase of product quality and potential new market opportunities. Personal environmental commitment (assumed to be an influential driver for the

implementation of a DFE option) apparently had little significance. The research showed quite clearly that by far the most important external stimuli for DFE are customer demands and governmental legislation. Furthermore, this study revealed that three of the eleven barriers distinguished must be characterized as 'no-go' barriers: their existence obstructs the DFE options in question from being implemented. The other eight barriers were only 'initial' barriers. If driven by several influential stimuli, DFE options with an initial barrier were still implemented.

Conclusions regarding the DFE performance of SMEs

The DFE performance of the companies as a result of the IC EcoDesign project was measured by means of three indicators: DFE focus, DFE result and DFE learning.

DFE focus A hierarchical cluster analysis was used to group the 60 companies that had prioritized at least one DFE option into eight so-called 'DFE focus clusters'. This was achieved on the basis of their focus with regard to DFE: the number and type of DFE principle of the DFE improvement options they had prioritized.

DFE result The companies' DFE result was measured by means of four DFE result indicators:
- DFE score: the extent to which a set of DFE improvement options, generated through the IC EcoDesign scan, had been realized;
- DFE project score: the extent to which a set of DFE improvement options with a high level of newness, generated through the IC EcoDesign scan, had been realized;
- DFE design impact: the researcher's opinion about the extent to which the product involved in the IC EcoDesign scan had been innovated;
- DFE result opinion: the opinion of the company's representative as to the extent to which the IC EcoDesign project had led to concrete results for the product in question.

About half of all the companies shared a relatively low *DFE score* and *DFE project score.* The scores of the other half were considerably higher. Two companies had achieved exceptionally high scores. This means that, as had been expected, the SMEs participating in the IC EcoDesign project differed considerably as to the extent to which they had implemented those DFE improvement options.

The companies also differed considerably with regard to *DFE design impact.* A 'major redesign' was recorded in 21 cases. This high DFE design impact was mainly achieved due to the impact of the set of DFE improvement options that had been prioritized by the companies. Although the DFE result was not measured in quantitative, environmental terms for each company, these findings indicate that in at least 21 companies considerable environmental product improvements had been achieved. Only in 5 cases had the EcoDesign project failed to lead to product improvements or research. In conclusion, the IC project had a considerable impact on the product, packaging and process designs involved.

With regard to the *DFE result opinion,* 48 out of 74 companies said that the IC EcoDesign project had resulted in moderate to high concrete results. Only 8 of the 74 companies said that the project had not led to any concrete result at all. The companies' appreciation of the project was thus 'fairly high'. The researchers' opinions about the result of the IC EcoDesign project in a certain company (DFE design impact) were in line with those of the companies themselves (DFE result opinion).

DFE learning The last indicator of DFE performance was a company's DFE learning, focusing on the extent to which the project had led to organizational or procedural changes in a company, and thus facilitating the utilization of DFE in future projects. DFE learning was operationalized by 47 different variables, later combined into the nine DFE learning indicators.

DFE learning was the ***highest*** regarding the following aspects:
- DFE objectives (integrating DFE in in-house product planning procedures);
- DFE management system integration (especially linking DFE to existing Environmental Management System or Quality System);
- DFE internal involvement (involvement of management and product developers);
- DFE awareness (increase of DFE-related knowledge);
- DFE follow-up activities (especially regarding the utilization of DFE experience for other products);
- DFE protocol (especially in terms of using a DFE checklist).

DFE learning was ***low*** in terms of:
- DFE policy (the companies hardly communicated their DFE initiatives in public documents);
- DFE external involvement (the companies hardly established DFE cooperation with external parties);

- DFE specification (companies hardly specified DFE requirements meant for external parties).

Later on, four of these nine DFE learning indicators were selected and combined into one, overall scale for DFE learning. The diverging scores on this scale emphasized that there was indeed a considerable difference among the companies in terms of the organizational or procedural changes they had accomplished. Another finding was that while the scores for the four DFE learning indicators were generally relatively low, they still showed a strong variance. This strong variance indicates that great care should be exercised when drawing conclusions for SMEs in general.

Understanding the differences in the companies' DFE performance

In order to obtain insight into the question why certain SMEs have a higher DFE performance than others (in terms of their DFE result and DFE learning) the correlation between four sets explanatory variables and the dependent variables of DFE result and DFE learning were studied. A total of 59 explanatory variables distinguished showed a substantial correlation with the companies' DFE result and/or DFE learning. About half of these 59 variables correlated considerably with the companies' DFE result *or* their DFE learning. The other 30 explanatory variables which correlated with both DFE result *and* DFE learning are regarded as sufficiently convincing indicators of a company's DFE performance. These variables are summarized in Figure 6 below.

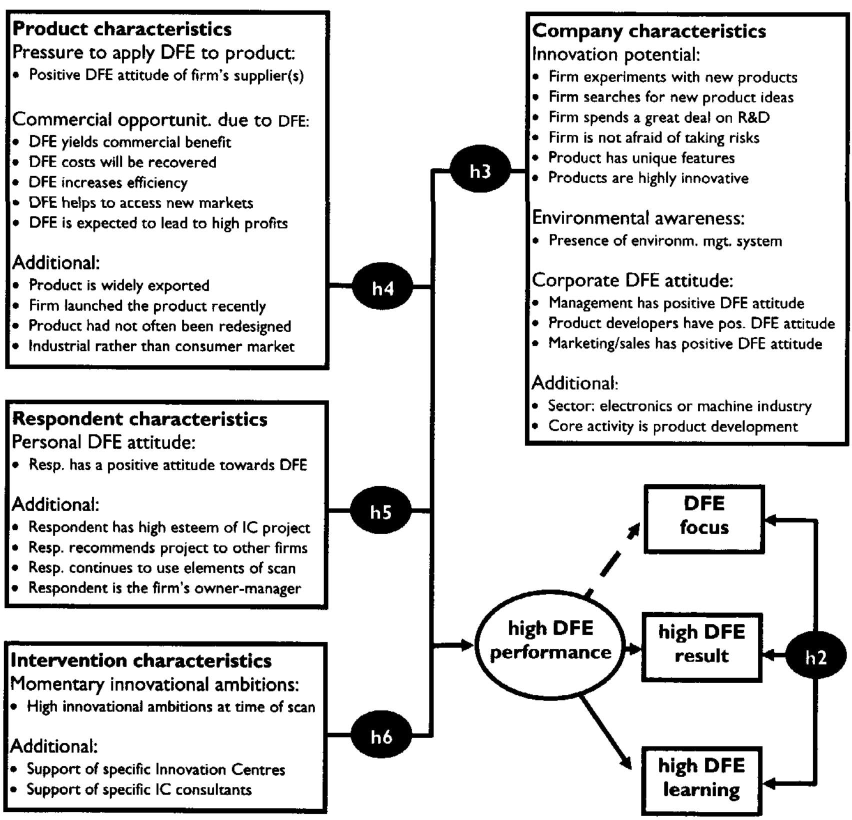


Figure 6 *Research model B with hypotheses 2 to 6 (h2 to h6); the explanatory variables included show a convincing correlation with the dependent variables DFE result and DFE learning*

Certain relations were obvious and confirmed by the study; this was not entirely to our surprise. The more significant findings were:

- Companies which sell their products to industrial markets seem to yield a higher DFE performance than those which focus on consumer markets. An explanation for this might be that industrial customers have more specific environmental demands than consumers.
- A company's DFE performance was the highest if the respondent was the company's owner-manager.
- The 'intervention characteristics' seem to be remarkably important. The empirical findings indicate that a company's DFE performance is strongly related to the moment of intervention as well as to the individual IC consultant involved.
- DFE performance is relatively high in innovative companies. These are companies that experiment, search actively for new product ideas, invest in R&D, dare to take risks and market products with unique product features or highly innovative products.
- Companies which had established an environmental management system (formal or informal) seemed to reveal a relatively high DFE performance.

C. Reflection on the hypotheses

Six hypotheses which underpinned research models A and B were defined. Most of them were broken down into a further two or three sub-hypotheses. The following summarizes the extent to which these hypotheses were supported by the empirical findings of this study.

1.A: Regarding the application of DFE in small and medium-sized enterprises, the actual influence of internal stimuli on the success rate of DFE principles is stronger than the influence of external stimuli. (Confirmed)

Hypothesis 1.A, which opposes the traditional line of thought in environmental management literature, was supported by the empirical findings of this study. The subsequent analyses of empirical findings, reported in Chapter 6, showed that internal stimuli seem to have a greater impact on the success rate of DFE improvement options than external stimuli in the companies' decision-making on the subject of DFE.
The only external stimuli of importance that were mentioned in this study were 'legislation' and the 'environmental demands of customers and end-users'. Yet the actual number of times these external stimuli were mentioned was very limited. Because of their (almost total) absence, the actual influence of external stimuli on SMEs is small.

1.B: Of all the internal stimuli that motivate an SME to implement DFE improvements, the personal environmental commitment of that company's owner-manager is the most influential factor. (Not confirmed)

Contrary to our expectations, the empirical findings did not support hypothesis 1.B. The analysis of the relation between the internal stimuli mentioned in connection with DFE options and their success rates showed that many of these options were still rejected despite the fact that the respondent was convinced of their environmental benefit. Only when they were supported by additional stimuli did the DFE options have a chance. The study showed that the most influential internal stimuli were 'innovative opportunities', 'increase of product quality' and 'new market opportunities'. Nevertheless, research findings in Chapter 7 show that personal environmental commitment was an important driver for a company to consider the application of DFE by participating in the IC EcoDesign project. However, in terms of decision-making on whether or not to realize DFE options, the impact of this stimulus seems to be limited.

1.C: The participants in the DFE EcoDesign project will reject DFE improvement options that are susceptible to the barriers 'insufficient complementarity', 'lack of interesting technological options' and 'insufficient appropriability'. (Not confirmed)

Hypothesis 1.C reflects the expectation derived from the capability theory that DFE improvement options must meet at least three requirements in order to become eligible for realization. Firstly, the theory says a DFE option must be complementary to existing product requirements. Secondly, a DFE option will only prioritized if technological options (alternative solutions for the relevant

environmental problem) already exist or if the company is interested in developing this technology itself. The third prerequisite for a DFE option to be prioritized is called 'appropriability': the DFE option must result in a commercial advantage that the company can appropriate.
The empirical findings do not support hypothesis 1.C as a whole. Insufficient complementarity and insufficient appropriability were apparently only 'initial barriers'. They were frequently mentioned, but they were not insuperable: their occurrence did not automatically block the realization of the DFE improvement concerned. Only the availability of suitable technological alternative solutions was a 'no-go barrier'. DFE options associated with this barrier were rejected or postponed for several years.
In addition to this no-go barrier, two other barriers (not mentioned in hypothesis 1.C) are prerequisites for realizing a DFE option. These additional 'no-go' barriers can be described as 'doubting the environmental benefit of the DFE option', and 'not feeling responsible for realization of the DFE option'.

2.A: Companies that manifest a good DFE result, as a result of the IC EcoDesign project, will also achieve a high level of DFE learning. (Confirmed)

The empirical findings of this study support hypothesis 2.A. Bivariate correlation analyses showed that the five indicators for DFE result and the five indicators for DFE learning were correlated to a moderate extent, ranging from 'slightly' to 'considerably'. This means that most companies with a high DFE result also revealed a relatively high level of DFE learning as well and vice versa.

2.B: Companies that manifest a good DFE result and a high level of DFE learning as a result of the IC EcoDesign project also have a comparable DFE focus. (Confirmed)

A cluster analysis showed that the companies studied could be clustered into eight 'DFE focus clusters' according to specific DFE focus (the type and number of DFE principles they had prioritized). The findings showed considerable correlation between the variable 'DFE focus cluster' and the ten indicators for DFE result and DFE learning. As assumed, this implies that companies belonging to a specific DFE focus cluster not only have a similar DFE focus, but a comparable DFE result and DFE learning too.

3.A: Companies with a high innovative potential have a higher DFE performance than less innovative companies. (Confirmed)

There is empirical evidence to support the assumption that the more innovative a company, the higher its DFE performance. Indicators for innovativeness that showed a considerable correlation with the DFE performance indicators were 'the extent to which a company experiments', 'searches actively for new product ideas', 'invests in R&D', 'markets products with unique product features or products that are highly innovative' (new in the industry to which the company belongs). This conclusion supports the notion that DFE can create synergy with more traditional targets in product development, like high product quality, durability, consumer friendliness and process efficiency. Companies able to reach these targets in their product development generally manifest a high level of DFE performance as well. Not all indicators for innovativeness supported this hypothesis to the same extent though. Further analysis is recommended to assess the interrelations between the indicators for innovativeness that were distinguished.

3.B: Companies with a high level of environmental awareness and activities have a higher DFE performance than companies with less environmental awareness and fewer activities. (Not confirmed)

In general, indicators of a company's DFE awareness (e.g. pursuing an environmental policy) were weakly correlated with the indicators for DFE performance. The only exception here was the presence of an Environmental Management System, which seems to be a good predictor for the relatively high DFE performance of a company. This finding indicates that an EMS could be a stepping stone towards DFE, and vice versa.

3.C: Companies with a positive attitude towards DFE will manifest a higher DFE performance than companies with a critical attitude. (Confirmed)

The analysis showed that particularly the DFE attitude of the company's management, its product development department, and its marketing/sales department, are good predictors of a high DFE performance in terms of DFE result *and* DFE learning. Correlation between the other indicators of a company's DFE attitude (the DFE commitment of the environmental, quality, purchasing and production departments) and DFE performance were not sufficiently convincing to further support this hypothesis.

Additional findings related to company characteristics

- There is substantial correlation between the *branch of industry* to which the company belongs and its DFE performance. The most DFE-active industries would seem to be the electronics industry and the machine industry.
- Another predictor of high DFE performance is a company's *core activity*; if a company regards product development as one of its core activities, then its DFE performance is generally high in terms of both DFE result and DFE learning. The few companies studied that are 'jobbers' or wholesalers seemed to feel less responsibility for DFE and generally wait for initiatives to be taken by companies positioned nearer to the source of the product supply chain.
- *Company size* (in terms of number of employees) bears no relation with its DFE performance.

4.A: Products subjected to external pressure with regard to their eco-efficiency will prompt a higher DFE performance than those which are not. (Confirmed)

Several sets of indicators were used to measure the amount of external pressure to implement DFE in connection with the products concerned. We found that of all the actors that boosted a company's DFE learning, the company's customers and end-users seem to be the most influential. This is in line with our earlier conclusion that the most influential external stimuli for DFE was customer demand.

4.B: Products for which DFE offers commercial opportunities will lead to a higher DFE performance than those for which DFE is perceived as commercially neutral or negative. (Confirmed)

Not surprisingly, good predictors for a high DFE performance were the extent to which a company regards DFE as a commercial opportunity, an initial investment which is recovered in due course, an opportunity to increase efficiency, a means of reducing production or transport costs, or a means of increasing market shares or entrance to new markets. Very convincingly correlated are the company's DFE performance and its estimation of the total commercial gains from DFE in two years' time. Here too should the word 'predictor' be used with great care: the causality of the relationships was not analyzed.

Additional findings related to product characteristics

An additional set of product characteristics was also explored. This led to some surprising findings. The DFE performance generally turned out to be the highest if the product was exported world-wide, if it had been recently launched, if it had not yet been redesigned (or only once), if it was in the growth stage of its commercial life cycle, if it had a short functional life time and if it was intended for an industrial market rather than the consumer or governmental market.

5.A: A high personal environmental commitment on the part of the company's representative contributes towards DFE performance. (Not confirmed)

Only a weak correlation was found between the respondent's personal environmental commitment and the company's DFE performance. This finding supports our earlier conclusion - related to hypothesis 1.B - that to boost the utilization of DFE in a small company, the personal environmental commitment of the company's owner-manager is essential. However, when it comes to decision-making on the realization of DFE options, the impact of this stimulus seems to be limited.

5.B: If the company's representative has a positive attitude towards DFE the DFE performance will be higher than in case he has a critical attitude. (Confirmed)

As expected, considerable correlations were found between the respondent's attitude towards DFE and the indicators of DFE performance. The results may, however, have been influenced by the fact that good project results (in terms of high DFE performance) probably resulted in a positive attitude towards DFE. The fact that, contrary to hypothesis 5.A, hypothesis 5.B is apparently supported by empirical evidence, might appear contradictory: persons with a positive attitude towards DFE are supposed to have a high level of environmental commitment as well. This contradiction is probably due to the operationalization of the two hypotheses 5.A and 5.B.

Additional findings in connection with respondent characteristics

The findings showed that, as expected, respondents who were highly *appreciative* of the (results of) IC EcoDesign project generally belonged to those companies that had a relatively high DFE performance. Furthermore, the respondent's *position* seems to be connected with the company's DFE performance: if the respondent was also the company's owner-manager, DFE performance was relatively high.

6: *Only if a consultant enters a company at such a time when the company's innovative ambitions are high, will the intervention lead to a high level of DFE performance. (Confirmed)*

As assumed, a convincing predictor of a company's DFE performance seems to be its 'momentary innovational ambitions'. If the company had the ambition to redesign the product at the moment the Environmental Innovation Scan was performed, the chances of a significant DFE performance were relatively high. This corresponds with a research finding related to hypothesis 4 that if a product is in the growth stage the DFE performance is apparently higher than when going through one of the three other stages of its commercial life cycle (introduction - growth - maturity - decline).

Additional findings in connection with intervention characteristics

The influence of the individual *IC consultant* on the company's DFE performance was also investigated. This turned out to be unexpectedly high. Whether this depends, for instance, on the consultant's knowledge, his or her consulting style, or attitude towards the subject of DFE, is an important subject for further study.

D. Recommendations

Recommendations for future research

Recommendations for improving the DFE strategy wheel are:

- *Developing heuristics for DFE:* It would seem feasible and valuable to study whether DFE advice can be formulated from an environmental point of view for specific product groups. To start with, the results of already completed life cycle assessments can be aggregated into DFE heuristics, conceived for each product group distinguished.
- *Anticipating synergy and conflicts between DFE principles:* In the study which is the subject of this thesis attention was limited to the interaction between DFE principles on the one hand, and traditional product requirements on the other. Identifying and describing the synergy and conflicts between DFE principles mutually, and between DFE principles and other product demands, is still a valuable subject for future research.

Recommendations for improving our understanding of DFE learning processes in companies are:

- *Understanding DFE learning in industry:* This study showed that companies differ considerably in terms of DFE learning. However, it does not reveal the various aspects of DFE learning (like DFE checklists, follow-up activities) or how intensively they are used in corporate development practice. This issue is worth studying in more detail in future research. We agree with Gladwin (1993: 43) that existing organization theory could provide the necessary theoretical fundament. Moreover, the importance of strategic management theory in this respect is acknowledged.
- *Understanding the relationships between EMS, DFE and PEMS:* The findings of this research indicate that an EMS could be a stepping stone towards DFE, and vice versa. It would be interesting to study to the extent to which EMS and DFE enhance or oppose each other in product development practice. This question is particularly relevant since the Dutch Government has introduced a support scheme to promote the implementation of 'product-oriented environmental management system' (PEMS) in industry.

Recommendations for intermediary organizations with a view to the implementation of DFE in SMEs

In short, the study showed that the IC EcoDesign project in 1995 had the following results:

- 247 (41%) of all 596 DFE improvement options suggested to the 77 SMEs interviewed were prioritized, implying that they had either been realized or would be realized within 4 ½ years of having received the EcoDesign advice. Of these 247 DFE options prioritized, 183 (74% of 247; 31% of 596) had already been implemented.
- 60 out of 77 companies studied had prioritized at least one DFE improvement option. This means that the option will be implemented within 4,5 years after it was suggested to the company.
- One-third of the DFE options prioritized was completely new for the companies involved; another one-third was familiar, but was considered thanks to the IC EcoDesign project; the SMEs had considered the last one-third of the DFE options regardless of the IC EcoDesign project.
- In 21 companies (out of 77 companies studied) the IC EcoDesign project contributed towards 'major product redesigns'.

These findings prove that the IC EcoDesign project approach was effective. More than once did the companies characterize the project as a 'catalyst', starting or accelerating the process of application of DFE in their company.

This study led to the following suggestions for further improvement of the IC EcoDesign project. It goes without saying that these suggestions will be of value to other intermediary organizations as well.

- *Careful selection and proper training of consultants:* This study has made it clear that the role and influence of the consultants with respect to DFE is very important. Whether this depends on the consultant's knowledge, his or her consulting style or attitude towards the subject of DFE, is not clear. A point for future concern and (preferably) research is how this influence can be explained and what characterizes those IC consultants who arouse significant DFE performance.
- *Careful selection of companies:* We recommend intermediary organizations like the Innovation Centre Network to be more selective when choosing the companies for participation in a project like the IC EcoDesign project. Companies which regard product development as their core activity and which have high innovational ambitions at the moment of intervention are to be preferred.
- *Enhancing the product supply chain approach:* According to this study, a very influential barrier towards DFE arises if companies do not feel responsible for implementing a certain DFE improvement option. If such a barrier exists, the DFE process comes to a halt. To prevent this we would suggest that intermediaries focus their attention on product supply chains as well as on the individual companies. If a product supply chain is considered as a whole it is possible to 'redistribute' DFE responsibilities to companies which are, and indeed feel they are, responsible.
- *Suggesting convincing DFE improvement options:* A very influential barrier standing in the way of realizing a DFE option arises if a company doubts the environmental benefit of the suggested DFE option. We recommend consultants to be critical about the actual environmental benefit of the DFE improvement options they suggest in DFE action plans and to make sure that the company is convinced of this environmental benefit.
- *Promoting benchmarking:* The activities of competitors were apparently very strong external stimuli, even though they were not mentioned frequently. It could therefore be worthwhile confronting SMEs more directly with the DFE initiatives of their competitors - if any - by means of environmental benchmarking.
- *Providing extensive follow-up support*: The IC EcoDesign project approach could be improved upon by ensuring more extensive follow-up support of the IC consultant involved.

Recommendations for small and medium sized enterprises

- *Starting an ecodesign pilot project*: A good way to start taking environmental issues into consideration in product development is to start up an in-house ecodesign pilot project. A project of this kind is best if it is focused on a product the company would like to redesign anyway. As this study shows, ecodesign can serve as a stimulus to re-think a product's design; it can also lead to a variety of additional advantages. This opportunity should not be missed.
- *Asking for assistance*: SMEs are recommended to link up with existing ecodesign support programmes. Since SMEs are known to be kept busy dealing with their day-to-day business affairs, we recommend that they ask for external assistance (which is readily available these days).

- *Incorporating DFE*: The advice after a company has applied ecodesign principles in a pilot project is to proceed with incorporating ecodesign in its development procedures, for example by means of an ecodesign checklist. The company is then advised to set its ecodesign targets for the coming three years.
- *Aiming for environmental policy*: We recommend that a company decides on the actions to take on environmental issues for all company functions at the same time in order to have a complete point of reference for the coming years. ISO 14.001 could offer an appropriate framework for that, even if a company is not aiming for ISO 14.001 certification.
- *Joining forces horizontally as well as vertically*: SMEs in particular could benefit from cooperating with other companies. Horizontal cooperation might convince suppliers to develop more eco-efficient technologies or materials. It also enables common ecodesign target-setting (at branch of industry level); this is necessary for communication with governmental legislative bodies. Vertical cooperation (cooperation with companies in the same product supply chain) is also recommended. Vertical cooperation helps to (re)designate ecodesign responsibilities to those partners in the product supply chain who really are - and feel - responsible for a specific ecodesign task.

Recommendations for industrial designers

- *Start with the most appealing DFE principles*: This study has shown quite clearly that ten of the 33 DFE principles are the most successful. We recommend that an industrial designer who wants to apply ecodesign should start by considering these ten DFE principles, assuming they are relevant. By doing this he will raise the company's enthusiasm for ecodesign.
- *Get commitment of top management*: This study indicates that an industrial designer should ensure the commitment of top management if he intends to apply ecodesign in a certain development process. Together, they should then go about setting ecodesign priorities. The management's commitment is also essential given that ecodesign demands extra attention, time and, consequently, resources.
- *Speak the company's language*: In order to convince decision-makers of a certain DFE improvement option, as well as to give them the arguments to convince others, the industrial designer is advised to set out the option's improvement potential on the basis of 'facts and figures'.
- *Use stimuli, discuss barriers:* This study showed which are the most influential stimuli and barriers for DFE. The designer is recommended to analyse which stimuli or barriers could influence his specific ecodesign proposal (see Figure 5). In addition to influential external stimuli, the company's interest could be raised by means of internal stimuli. The designer should also be aware of potential 'no-go' barriers. In that case he is advised to concentrate on DFE issues instead.
- *Investigate and stimulate developments of suppliers*: SMEs were recommended to ask for external assistance for ecodesign. It goes without saying that this also counts for industrial designers. This is a group that could particularly benefit from the knowledge among suppliers.
- *Apply DFE benchmarking:* Designers should investigate the ecodesign initiatives of competitors as well. If competitors claim that their products are more eco-efficient, the company is warned. If the competitors lag behind, the company could create a unique selling point.
- *Become a member of O2:* We recommend industrial designers, especially Dutch designers, to become members of O2 Nederland in order to increase their knowledge, draw inspiration and come into contact with others who use ecodesign in their daily work (tel. +31.10.411 81 02).

Recommendations for developers of policy for promoting DFE in industry

- *Proceeding with demonstration projects*: First of all, government should proceed to stimulate DFE demonstration projects like the IC EcoDesign project studied in this thesis. This study showed that the approach used in the IC EcoDesign project is very effective in the sense that it actually raised awareness and boosted activities connected with DFE among SMEs.
- *Proceeding with financial support schemes*: Financial support schemes are effective instruments to lower the threshold for SMEs to invest in DFE after the DFE intervention. SMEs sometimes find it difficult to apply for the existing financial support schemes, probably because of the related time schedules and necessary administration. We therefore recommend that these schemes should be adjusted to bring them more into line with day-to-day practice in SMEs.
- *Promoting the commercial opportunities related to DFE*: This study showed that DFE obviously has commercial opportunities, especially for end products like those studied for this thesis. Spreading this idea is a good way of stimulating other companies to apply DFE. In addition to the

promotional activities of the Innovation Centres, government should ensure the promotion of ecodesign at national level.

- *Providing strong and consistent external stimuli:* The study shows that the SMEs studied implement mainly those DFE options that generate commercial benefit. How to motivate companies to realize DFE options with a larger environmental benefit, but which have less interesting commercial opportunities? The empirical findings imply that to boost the application of DFE in SMEs, the amount and variety of external pressure could be increased. The *market pull* could be given a boost in order to increase the amount of external pressure. For that, the study lists several suggestions. Furthermore, *eco-benchmarking by consumer organizations* seems to have a strong influence on the DFE behaviour of manufacturers and should be continued.
  While it is more or less non-existent at this moment, *government task-setting* is believed to offer important external drivers towards DFE as well, especially for companies that just 'wait and see'. Government task-setting in connection with DFE (e.g. the Dutch system of environmental covenants) could have a direct influence on the environmental initiatives of SMEs, or an indirect influence by promoting DFE application in larger companies which in turn will pass their DFE demands onto their SME suppliers.
  Companies - especially SMEs - are recommended to organize themselves in *industrial sectors*, so they can set up DFE initiatives and tasks that apply to the sector as a whole. In doing so, companies stimulate each other and could prevent free-riding.
  Finally, it is recommended that *environmental organizations*, as well as *financial institutions*, could act as external drivers for DFE.
- *Applying a sector-specific approach:* The study showed that certain branches of industry (the electronics industry and the machine industry) were far more positive towards DFE than others. Furthermore, the industrial sector initiatives have proved themselves to be an influential stimulus towards DFE. This forces us to conclude that a sector-oriented approach is recommended in the process of promoting DFE.
- *Boosting product-oriented EMS:* In 1997 the Dutch Government launched a scheme to promote the establishment of 'product-oriented environmental management systems' (PEMS) in Dutch industry (in Dutch: *Productgerichte Milieuzorg* or PMZ). This PEMS scheme encourages companies that already use DFE incidentally to safeguard the implementation of DFE in future development projects by means of improved management procedures. The findings of this study support this policy. We therefore recommend the 'down-scaling' of PEMS into a partial or informal PEMS that meets the particular requirements of the SME sector. The Innovation Centres could take a leading role in the implementation of such SME-specific PEMS in industry.
- *From ecoredesign to ecodesign*: So far, the companies studied revealed DFE results that can be typified as 'ecoredesigns' or 'incremental green designs'. For the future, it would be worthwhile approaching SMEs with a programme which is focused more clearly on promoting 'ecodesigns' or 'sustainable product designs', learning from experience with the existing ecoredesign approach. By doing this industry could benefit even more from the innovational potential of design for environment.

Samenvatting

'EcoDesign empirisch onderzocht; milieugerichte productontwikkeling in het Nederlandse midden- en kleinbedrijf.' Proefschrift van Carolien G. van Hemel.
Dit proefschrift onderzoekt de initiatieven op het vlak van milieugerichte productontwikkeling van 77 kleine tot middelgrote bedrijven die in 1995 deelnamen aan het IC EcoDesign project van het Innovatie Centrum Netwerk Nederland.

A. Opzet van het onderzoek

Waarom dit onderzoek?

Tot op heden richtte literatuur over milieumanagement zich voornamelijk op de implementatie van milieuzorgsystemen, schoonmaaktechnologie en schonere technologie. Men concentreerde zich hierbij op het milieumanagement van grote industriële bedrijven. Hoewel steeds meer bedrijven de laatste jaren aandacht besteden aan milieugerichte productontwikkeling (MPO of ecodesign) is de wijze waarop zij dit doen nog nauwelijks onderzocht, zeker niet door empirisch, vergelijkend en verklarend onderzoek. Deze constateringen leidden tot de doelstelling van dit onderzoek: Meer te leren over de initiatieven van kleinere bedrijven op het gebied van milieugerichte productontwikkeling.

De empirische bron van dit onderzoek werd gevormd door het 'IC EcoDesign project' van het InnovatieCentra Netwerk Nederland. Dit project, dat liep van 1995 tot 1998, had ten doel om het Nederlandse midden- en kleinbedrijf (MKB) vertrouwd te maken met het onderwerp milieugerichte productontwikkeling (of 'ecodesign'). De schrijfster van dit proefschrift was van het begin af aan betrokken bij dit project. Mede daarom bood het IC EcoDesign project een goede gelegenheid om een onderzoek te doen naar de ecodesign initiatieven van 77 kleine tot middelgrote bedrijven.

Onderzoeksvragen

Het onderzoek concentreerde zich op de volgende twee onderzoeksvragen:
A. Waarom hebben sommige ecodesign strategieën meer succes dan andere?
B. Waarom hebben sommige bedrijven meer succes bij het toepassen van ecodesign dan andere?

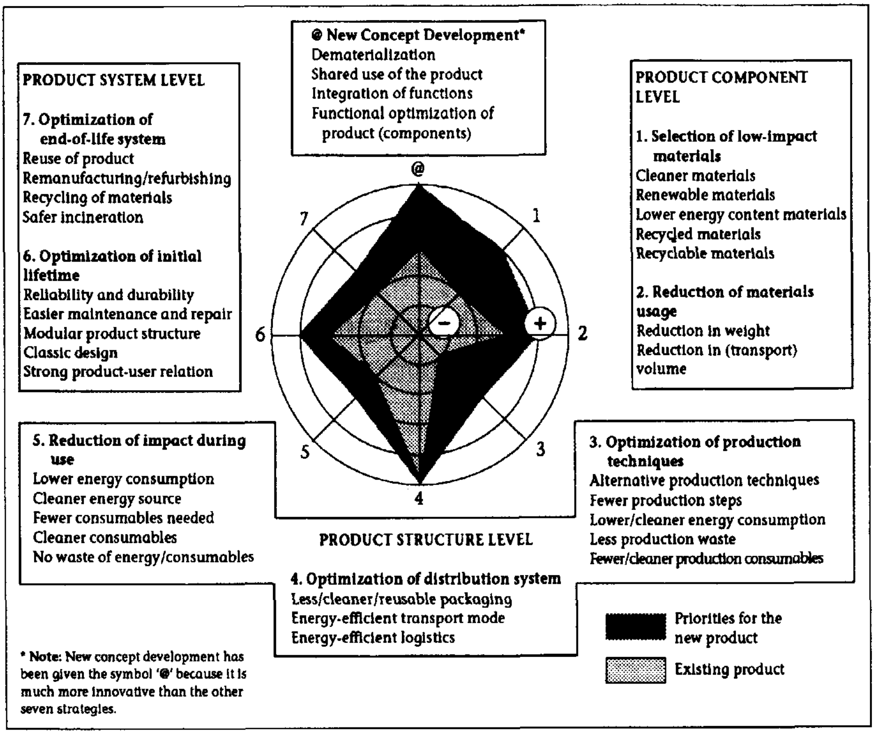
Onderzoeksvraag A is opgesplitst in de volgende drie deelvragen:
A.1 Hoe kan het succes van ecodesign strategieën gemeten worden?
A.2 Hoe succesvol zijn de verschillende ecodesign strategieën?
A.3 Hoe kan het verschil in succes van de verschillende ecodesign strategieën verklaard worden?

Evenzo is onderzoeksvraag B opgesplitst in drie deelvragen:
B.1 Hoe kan de ecodesign prestatie van een bedrijf dat deelneemt aan het IC EcoDesign project gemeten worden?
B.2 Wat zijn de verschillen in ecodesign prestatie van de deelnemende bedrijven?
B.3 Hoe kunnen deze verschillen worden verklaard?

De antwoorden op deze vragen helpen ons te begrijpen wat kleinere bedrijven beweegt om ecodesign toe te passen. Met deze kennis kunnen we eventuele barrières voor ecodesign wegnemen en kleinere bedrijven stimuleren ecodesign te implementeren.

Het ecodesign strategieënwiel

Bij aanvang van dit onderzoek werd, op basis van literatuuronderzoek, het zogenaamde 'ecodesign strategieënwiel' ontwikkeld. Dit model speelde een belangrijke rol in het IC EcoDesign project en in het hier beschreven onderzoek. Het ecodesign strategieënwiel is gebaseerd op een typologie van 'ecodesign strategieën' en 'ecodesign principes'. Deze typologie is bedoeld om de ecodesign voorkeuren van de onderzochte bedrijven te kunnen typeren. De ecodesign typologie onderscheidt 33 ecodesign principes: mogelijke richtingen om een product milieukundig te kunnen verbeteren, waarbij gekeken wordt naar de gehele productlevenscyclus van het betreffende product. Deze 33 ecodesign principes zijn geclusterd in 8 ecodesign strategieën. Figuur 1 geeft het ecodesign strategieënwiel weer.



Figuur 1 Het ecodesign strategieënwiel (Van Hemel and Brezet, 1997; gebaseerd op Van Hemel, 1994)

Het IC EcoDesign project

Het doel van het IC EcoDesign project was om het Nederlandse midden- en kleinbedrijf (MKB) kennis te laten maken met ecodesign en het te stimuleren ecodesign daadwerkelijk toe te passen bij zijn productontwikkeling. Voor dit project werd een speciale interventiemethodiek ontwikkeld, o.a. gebaseerd op eerdere ecodesign ervaringen. Een belangrijk onderdeel van deze methodiek was de 'Milieu Innovatie Scan', toegepast door adviseurs van het Innovatie Centra Netwerk.
De Milieu Innovatie Scan, met daarin opgenomen een kwalitatieve levenscyclusanalyse, leidde direct tot een aantal milieukundige verbeteropties voor het bestudeerde product. Zodoende bood de scan een groot aantal kleinere bedrijven de gelegenheid een start te maken met ecodesign, zonder dat eerst kwantitatieve, gedetailleerde levenscyclusanalyses (LCA) gemaakt moesten worden. Na uitvoering van de scan bestond de mogelijkheid dit alsnog te doen.

Deelnemende bedrijven

In 1995 namen 94 bedrijven deel aan het IC EcoDesign project; 77 van deze 94 bedrijven waren bereid deel te nemen aan het hier beschreven onderzoek. Voor de bedrijven die aan het IC EcoDesign project wilden deelnemen golden de volgende criteria:
1. Zij moeten behoren tot het MKB, gedefinieerd als bedrijven met maximaal 200 medewerkers;
2. Zij moeten 'zelfspecificerend' zijn, wat wil zeggen dat zij zelf de productspecificaties opstellen;
3. De productontwikkeling vindt plaats in Nederland;

4. De producten zijn tastbare, fysieke producten.
Het vinden van bedrijven die wilden deelnemen aan het IC EcoDesign project en aan deze vier criteria voldeden ging wat moeizamer dan verwacht.

De deelnemende bedrijven behoorden tot veel verschillende bedrijfstakken. De meest voorkomende branches waren de metaalproductenindustrie, de machine-industrie en de hout- en meubelindustrie, gevolgd door de rubber- en kunststoffenindustrie, de electrotechnische industrie en de textielindustrie. Maar liefst 70% van de onderzochte bedrijven hebben minstens één productontwikkelaar in dienst. Bijna alle onderzochte bedrijven zijn inderdaad zelfspecificerend en produceren eindproducten. Over het algemeen hadden de bedrijven bij aanvang van het IC EcoDesign project nog weinig milieu-initiatieven ontplooid; 75% van de bedrijven had geen enkele ervaring met ecodesign.

Producten

De producten die centraal stonden tijdens de Milieu Innovatie Scans waren even divers als de bedrijven die ze voortbrengen. Ze liepen uiteen van een verpakking tot een touringcar. Ze verschillen niet alleen qua materiaalgebruik, grootte, complexiteit, productietechnieken en distributiewijzen, maar ook ten aanzien van hun functies, soort en grootte afzetmarkt, levensduur etcetera.

Methode van onderzoek

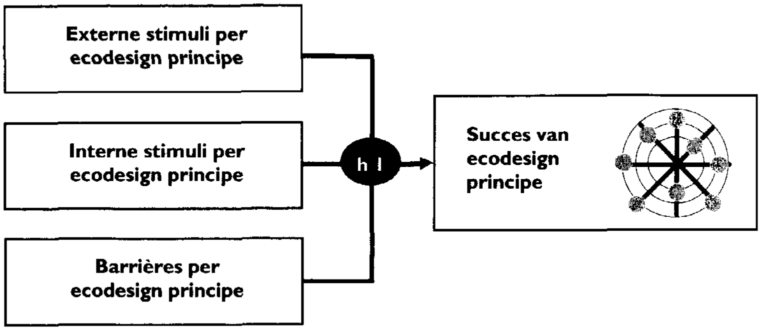
Het hier beschreven onderzoek kan getypeerd worden als vergelijkend, empirisch, kwantitatief veldonderzoek. Een zestal hypothesen is gedefinieerd. Empirische gegevens worden benut om te beoordelen of deze hypothesen verworpen of bevestigd worden. Deze gegevens zijn afkomstig van 77 van de 94 bedrijven die in 1995 deelnamen aan het IC EcoDesign project (het 'veld'). Vanwege het geringe aantal van 77 cases zijn alleen relatief eenvoudige, bivariate statistische analyses uitgevoerd. De dataverzameling vond plaats door middel van een telefonisch interview en, ter aanvulling, een schriftelijke vragenlijst. De respondent die geïnterviewd werd was altijd tevens degene die de schriftelijke vragenlijst invulde. In de meeste gevallen was hij of zij de eigenaar-manager van het bedrijf; in een aantal grotere bedrijven was deze persoon het hoofd van de productontwikkelingsafdeling.

Het onderzoek was gericht op de bovengenoemde twee onderzoeksvragen, elk uitgesplitst in drie deelvragen. Deze vragen zijn verder uitgewerkt in twee onderzoeksmodellen A en B, die in combinatie het conceptuele onderzoeksmodel van deze studie vormden.

Onderzoeksmodel A

Onderzoeksmodel A (geïllustreerd in Figuur 2) maakt duidelijk vanuit welk perspectief de vraag 'Waarom hebben sommige ecodesign principes meer succes dan andere?' is onderzocht. Uit literatuur over milieumanagement en ecodesign zijn drie groepen factoren afgeleid waarvan wordt verwacht dat zij het succes van ecodesign principes beïnvloeden: externe stimuli, interne stimuli en barrières (zowel intern als extern).

De IC adviseurs hadden - als resultaat van de Milieu Innovatie Scan - een totaal van 596 zogenaamde 'ecodesign verbeteropties' geadviseerd aan de 77 onderzochte MKB-bedrijven. Per bedrijf liep dit aantal uiteen van 3 tot 17 opties. Tijdens telefonische interviews ging de onderzoeker vervolgens voor iedere ecodesign verbeteroptie na in welke mate het geïnterviewde bedrijf de optie had geïmplementeerd. Tevens werd per optie in kaart gebracht wat de stimuli en barrières waren die het bedrijf hadden gemotiveerd c.q. weerhouden om de optie te implementeren.



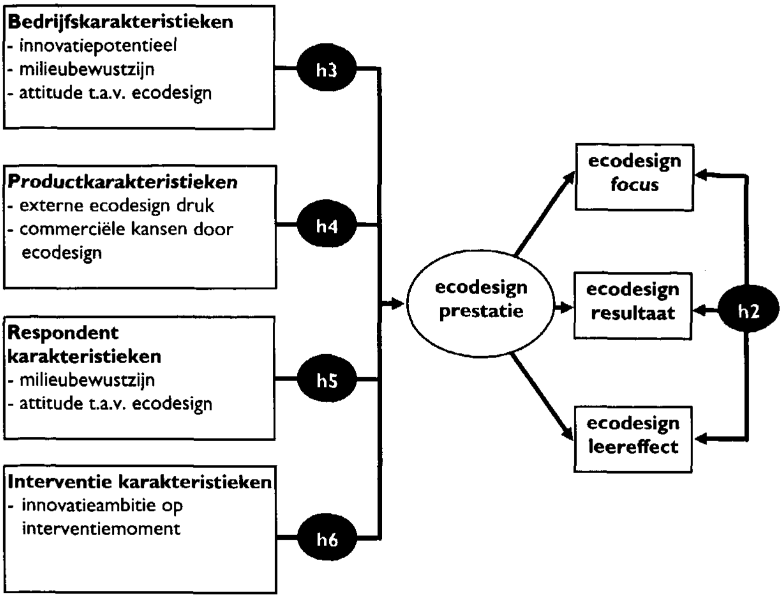
Figuur 2 *Onderzoeksmodel A met hypothese 1 (h1), bestaande uit de subhypothesen 1.A, 1.B en 1.C*

Onderzoeksmodel B

Onderzoeksmodel B (geïllustreerd in Figuur 3) vormde het tweede deel van het conceptuele onderzoeksmodel. Het visualiseert de benadering die gehanteerd is bij beantwoording van de tweede centrale onderzoeksvraag 'Hoe kan het verschil in ecodesign prestatie tussen de verschillende bedrijven worden verklaard?'. Het geeft aan dat het begrip 'ecodesign prestatie' is geoperationaliseerd door de volgende drie ecodesign prestatie-indicatoren:

- Ecodesign focus: De keuzes van een bedrijf ten aanzien van de typen ecodesign principes die het implementeert als resultaat van het IC EcoDesign project;
- Ecodesign resultaat: De concrete milieukundige verbeteringen in het product, de verpakking of de productieprocessen die een bedrijf weet te realiseren, als resultaat van het IC EcoDesign project;
- Ecodesign leereffect: De mate waarin een bedrijf heeft geleerd van het IC EcoDesign project en in staat en gemotiveerd is om in de toekomst ecodesign zelfstandig toe te passen.

Verder toont onderzoeksmodel B het perspectief bij beantwoording van de vraag waarom bepaalde bedrijven een hogere ecodesign prestatie tonen dan andere. De verwachting was dat de ecodesign prestatie van een bedrijf afhangt van een combinatie van factoren, waaronder bedrijfskarakteristieken, productkarakteristieken, karakteristieken van de respondent en interventiekarakteristieken. Toen het onderzoek werd opgezet was er nog geen geschikte theorie voorhanden die gebruikt kon worden als basis om de verschillen tussen de bedrijven te verklaren. Daarom is het huidige onderzoek exploratief van aard: uit de literatuur is een verzameling uiteenlopende karakteristieken afgeleid die de ecodesign prestatie van bedrijven mogelijk kunnen verklaren. Deze groep karakteristieken is vervolgens geclusterd in de bovengenoemde vier groepen behorende bij hypothesen 3, 4, 5 en 6 (zie Figuur 3).



Figuur 3 *Onderzoeksmodel B met hypothesen 2 tot 6 (h2-h6), alle bestaand uit diverse subhypothesen*

Natuurlijk zou ook de relatie tussen de onderzoeksmodellen A en B onderzocht kunnen worden. De bovengenoemde karakteristieken, de ecodesign prestatie en de stimuli en barrières die een bedrijf waarneemt zijn niet onafhankelijk van elkaar. Echter, het bestuderen van de relatie tussen de stimuli en barrières per ecodesign principe, genoemd door een bedrijf, en de betreffende bedrijfs- en productkarakteristieken valt buiten de doelstelling van dit onderzoek.

B. Onderzoeksresultaten

Conclusies over het succes van ecodesign principes

In totaal waren 596 ecodesign verbeteropties aan de 77 onderzochte MKB-bedrijven geadviseerd. Per verbeteroptie is nagegaan in welke mate de optie was gerealiseerd. Hiervoor werd een schaal met negen 'implementatiegraden' gebruikt. Tevens is onderzocht welke stimuli en barrières volgens de onderzochte MKB-bedrijven leidden tot implementatie versus afwijzing van de optie.
Vervolgens is de ecodesign typologie gebruikt om al deze 596 ecodesign verbeteropties in te delen naar ecodesign principe type.
Zodoende ontstond een overzicht van het succes van de 33 ecodesign principes, onderscheiden in de ecodesign typologie. Een ecodesign principe is zeer succesvol als een groot aantal opties van dit type is geadviseerd én geïmplementeerd. Bovendien was bekend wat de stimuli en barrières per ecodesign principe zijn, als aangegeven door de geïnterviewde bedrijven.

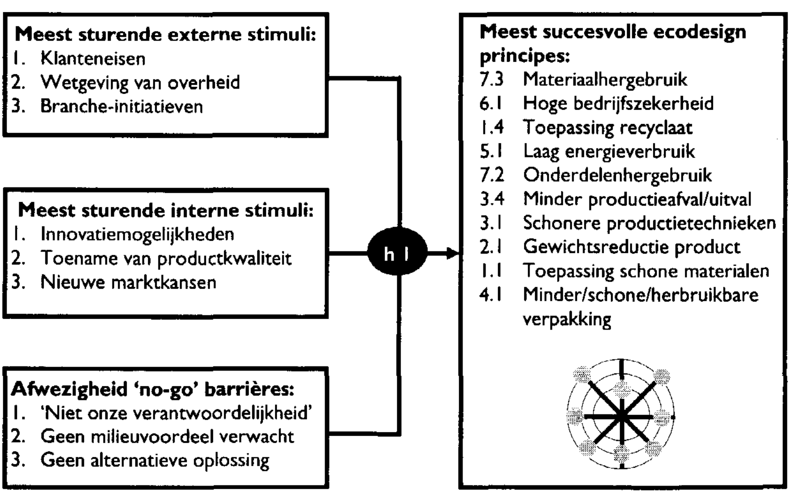
De conclusies van deze analyse, beschreven in hoofdstukken 5 en 6, zijn samengevat in Figuur 4 en Figuur 5. Figuur 4 toont de meest opvallende stimuli en barrières voor ecodesign, zowel wat betreft het aantal keren dat ze voorkomen als wat betreft hun invloedsrijkheid.

	Externe stimuli	Interne stimuli	Barrières
Hoe vaak genoemd?	130	795	414
Voor hoeveel van de 596 verbeteropties?	111 (19%)	339 (62%)	322 (54%)
Welke stimuli/barrières zijn het meest genoemd?	1. Klanteneisen (56) 2. Wetgeving van overheid (43) 3. Initiatief toeleverancier (16)	1. Verwachte milieuwinst (201) 2. Kostenbesparing (177) 3. Imagoverbetering (102)	1. Conflict met funct. producteisen (108) 2. Geen milieuvoordeel verwacht (51) 3. Commercieel nadeel (51)
Welke stimuli/barrières zijn het meest invloedrijk?	1. Klanteneisen 2. Wetgeving van overheid 3. Branche-initiatieven	1. Innovatieve mogelijkheden 2. Toename productkwaliteit 3. Nieuwe marktkansen	1. Men voelt zich niet verantwoordelijk 2. Geen milieuvoordeel verwacht 3. Geen alternatieve oplossing aanwezig

Figuur 4 *Overzicht van het aantal genoemde stimuli/barrières, het aantal ecodesign opties waarvoor een stimuli/barrière was genoemd, en de top drie van stimuli/barrières gezien hun voorkomen en gezien hun invloedsrijkheid*

Figuur 4 toont dat het aantal interne stimuli genoemd door de geïnterviewde MKB-bedrijven aanzienlijk hoger was dan het aantal externe stimuli: 795 interne stimuli waren genoemd voor 339 van de 596 opties (62%), terwijl slechts 130 externe stimuli waren genoemd voor 111 van de 596 opties (19%). Vervolgonderzoek toonde aan dat interne stimuli niet alleen vaker werden genoemd dan externe stimuli, maar dat ze ook een grotere invloed hadden op de overlevingskansen van de geadviseerde verbeteropties.

Figuur 5 vat de onderzoeksresultaten samen naar aanleiding van onderzoeksvraag A; het geeft aan wat de tien meest succesvolle ecodesign principes waren en welke stimuli en barrières het meest invloedrijk zijn gebleken.



Figuur 5 *Onderzoeksmodel A met de meest invloedrijke stimuli en barrières voor ecodesign en de tien meest succesvolle ecodesign principes (h1: hypothese 1)*

Het onderzoek toonde aan dat de onderzochte MKB-bedrijven de meeste aandacht gaven aan de einde-levensduur aspecten (materialen- en onderdelenhergebruik), aan een lager productgewicht, en aan de selectie van schonere en gerecycleerde materialen. Andere belangrijke aandachtspunten waren verhoging van de bedrijfszekerheid, verlaging van het energieverbruik en schonere technologie (minder productie-uitval en -afval, schonere productieprocessen). Ook de verpakking van het product werd vaak milieukundig verbeterd.

Figuur 5 toont verder dat verwachte innovatiemogelijkheden, verhoging van productkwaliteit en nieuwe marktkansen de meest invloedrijke interne stimuli waren. De mogelijke milieuwinst bleek minder invloedrijk dan verwacht. Veruit de meest invloedrijke externe stimuli waren klanteneisen en wetgeving. Verder toonde het onderzoek dat drie van de elf onderscheiden barrières kunnen worden getypeerd als 'no-go' barrières: als zij optreden heeft de ecodesign verbeteroptie in kwestie een zeer geringe kans geïmplementeerd te worden. De overige acht zijn getypeerd als 'initiële' barrières: als er voldoende stimuli voor een ecodesign verbeteroptie zijn is de kans groot dat deze geïmplementeerd wordt, ondanks het optreden zo'n initiële barrière.

Conclusies over de ecodesign prestatie van de onderzochte MKB-bedrijven

De ecodesign prestatie van de bedrijven, als resultaat van het IC EcoDesign project, is gemeten met behulp van drie prestatie-indicatoren: ecodesign focus, ecodesign resultaat en ecodesign leereffect.

Ecodesign focus Met behulp van een hiërarchische clusteranalyse zijn de 60 bedrijven die minstens één verbeteroptie gaan implementeren gegroepeerd in acht 'ecodesign focus clusters'. Deze clustering vond plaats op basis van het aantal en type ecodesign verbeteropties dat een bedrijf zou gaan implementeren of reeds geïmplementeerd had.

Ecodesign resultaat Dit werd gemeten aan de hand van vier ecodesign resultaat indicatoren:

- Ecodesign score: de mate waarin de set ecodesign verbeteropties, gegenereerd door middel van de Milieu Innovatie Scan, is geïmplementeerd;
- Ecodesign project score: de mate waarin de ecodesign verbeteropties die nieuw waren voor het bedrijf, gegenereerd door middel van de Milieu Innovatie Scan, zijn geïmplementeerd;
- Ecodesign ontwerpimpact: de mening van de onderzoeker over de mate waarin het product dat centraal stond bij de Milieu Innovatie Scan daadwerkelijk milieukundig is verbeterd;
- Ecodesign waardering: de mening van de respondent over de mate waarin het IC EcoDesign project in zijn bedrijf heeft geleid tot concrete resultaten.

De helft van de bedrijven hadden een relatief lage *ecodesign score* en *ecodesign project score*. De scores van de overige bedrijven waren beduidend hoger. Twee bedrijven hadden uitzonderlijk hoge scores. De conclusie is derhalve dat de onderzochte MKB-bedrijven inderdaad aanzienlijk verschillen in de mate waarin zij de geadviseerde ecodesign verbeteropties hebben geïmplementeerd.
De bedrijven verschilden ook sterk ten aanzien van hun score voor *ecodesign ontwerpimpact*. In 21 gevallen was het productontwerp 'sterk verbeterd'. In de beoordeling hiervan nam de onderzoeker alleen de verbeteropties geadviseerd in het IC EcoDesign project in ogenschouw. Omdat elk van deze opties met een zekere milieuwinst gepaard gaat betekent dit dat in minstens 21 bedrijven een aanzienlijke milieuwinst is geboekt. In slechts 5 bedrijven heeft het project tot geen enkele ontwerpverbetering of nader onderzoek geleid.
Met betrekking tot de ecodesign waardering meldden 48 van de 74 bedrijven dat het IC EcoDesign project 'enigszins' tot 'in sterke mate' tot concrete resultaten had geleid. In acht gevallen zei men dat het project tot geen enkel resultaat had geleid. De waardering van de bedrijven kan 'ruim voldoende' worden genoemd. De mening van de onderzoeker over het bereikte resultaat en die van de respondent blijken sterk overeen te komen.

Ecodesign leereffect De laatste ecodesign prestatie-indicator geeft aan in hoeverre een bedrijf in staat is in de toekomst zelfstandig ecodesign toe te passen. Het ecodesign leereffect was gemeten aan de hand van 47 variabelen die later tot 9 indicatoren voor ecodesign leereffect zijn gebundeld.

Het ecodesign leereffect van de bedrijven was relatief *hoog* inzake:

- Ecodesign doelstelling (integratie van ecodesign doelstellingen in het productbeleid);
- Integratie van ecodesign in het management systeem (in kwaliteits- of milieuzorgsysteem);
- Betrokkenheid van het bedrijf (van management en productontwikkelaars bij het project);
- Ecodesign kennistoename (zoals t.a.v. wetgeving, milieubelasting van toegepaste materialen);
- Ecodesign vervolgactiviteiten (met name in nieuwe ontwikkelingsprojecten);
- Ecodesign protocol (ontwikkeling en toepassing van een ecodesign checklist of handboek).

Het ecodesign leereffect was relatief *laag* ten aanzien van:

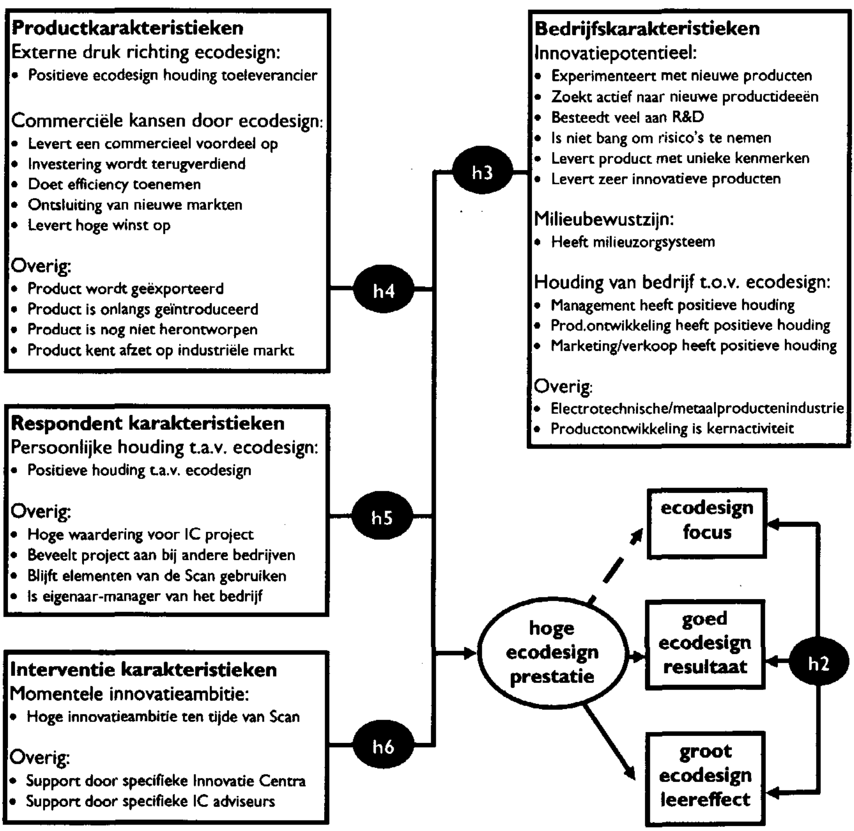
- Ecodesign beleid (ecodesign initiatieven worden nauwelijks genoemd in bedrijfspublicaties);

- Betrokkenheid van derden (geringe samenwerking met externe partijen inzake ecodesign);
- Ecodesign specificatie (bij uitbesteding worden ecodesign eisen nauwelijks gespecificeerd).

Later zijn vier van deze negen ecodesign leereffecten geselecteerd en gecombineerd in een enkele schaal voor ecodesign leereffect. Het feit dat bedrijven op deze schaal uiteenlopende scores hadden, geeft aan dat er een aanzienlijk verschil bestaat in het bereikte ecodesign leereffect bij de onderzochte bedrijven. Dit bevestigt eens te meer dat het trekken van conclusies voor 'het MKB' dikwijls niet geoorloofd is.

Hoe zijn de verschillen in ecodesign prestatie te verklaren?

Om een antwoord te vinden op de vraag waarom sommige MKB-bedrijven een hogere ecodesign prestatie hebben dan andere, zijn de correlaties tussen vier sets verklarende variabelen en de afhankelijke variabelen 'ecodesign resultaat' en 'ecodesign leereffect' bestudeerd.
In totaal bleken er 59 variabelen te zijn die aanzienlijk correleren met het ecodesign resultaat en/of ecodesign leereffect van de onderzochte bedrijven. Hiervan zijn er 30 die overtuigend correleren met beide afhankelijke variabelen, dus met ecodesign resultaat én met ecodesign leereffect. Hoewel nog geenszins vaststaat dat deze variabelen inderdaad de ecodesign prestatie van een bedrijf beïnvloeden, geven ze hiervoor wel een indicatie. Deze 30 variabelen zijn samengevat in Figuur 6.



Figuur 6 *Onderzoeksmodel B met de hypothesen 2 tot 6 (h2-h6); de getoonde verklarende variabelen correleerden met de afhankelijke variabelen 'ecodesign resultaat' én 'ecodesign leereffect'*

Sommige correlaties werden verwacht en zijn niet opmerkelijk. Een aantal meer opvallende bevindingen zijn:

- Bedrijven die hun producten afzetten op industriële markten lijken een hogere ecodesign prestatie te hebben dan zij die zich richten op de consumentenmarkt. Mogelijk stellen industriële klanten concretere milieueisen dan consumenten, of doen dit met meer overtuiging.
- De ecodesign prestatie was het hoogst indien de respondent de eigenaar-manager van het bedrijf was.
- De interventiekarakteristieken lijken erg invloedrijk. De correlatieanalyse doet vermoeden dat de ecodesign prestatie van een bedrijf sterk afhangt van het interventiemoment en van de betrokken IC adviseur.
- De ecodesign prestatie lijkt relatief hoog te zijn in de meer innovatieve bedrijven. Deze bedrijven kenmerken zich doordat ze durven te experimenteren, actief zoeken naar nieuwe productideeën, ruim investeren in R&D, niet bang zijn risico's te nemen en producten leveren die unieke kenmerken hebben of sterk innovatief zijn.
- Bedrijven die een milieuzorgsysteem hebben - al dan niet gecertificeerd - lijken een relatief hoge ecodesign prestatie te hebben geleverd.

C. Reflectie op de hypothesen

Ter concretisering van het conceptuele onderzoeksmodel was een zestal hypothesen gedefinieerd. De meeste hiervan bestonden uit twee of drie subhypothesen. Hieronder wordt samengevat in welke mate de hypothesen werden bevestigd door de onderzoeksresultaten.

1.A: Bij toepassing van ecodesign in het midden- en kleinbedrijf is de invloed van interne stimuli op het succes van ecodesign principes belangrijker dan de invloed van externe stimuli. (Bevestigd)

Hypothese 1.A, die niet overeenkomt met de gebruikelijke milieumanagement theorie, werd door de onderzoeksresultaten bevestigd. Een serie analyses, beschreven in hoofdstuk 6, toont aan dat in de besluitvorming over ecodesign interne stimuli meer invloedrijk zijn dan externe stimuli. De enige externe stimuli van belang waren 'milieuwetgeving' en 'milieueisen van klanten en eindgebruikers'. Echter, het aantal keren dat de onderzochte bedrijven deze stimuli noemden was zo gering, dat ze in de praktijk een zeer beperkte invloed lijken te hebben op de ecodesign besluitvorming van het MKB.

1.B: Van alle interne stimuli die het MKB motiveren om ecodesign verbeteringen te implementeren is het persoonlijk overtuigd zijn van het belang van ecodesign van de eigenaar-manager de meest invloedrijke. (Niet bevestigd)

Hypothese 1.B werd in dit onderzoek niet bevestigd. Het kwam regelmatig voor dat ecodesign verbeteropties werden verworpen hoewel de respondent overtuigd was van hun milieuwinst. De resultaten duiden erop dat een ecodesign optie alleen kans van slagen heeft indien deze wordt gemotiveerd door meer stimuli dan alleen de verwachte milieuwinst. Zeer invloedrijke interne stimuli bleken op te treden indien een ecodesign optie 'innovatiemogelijkheden', 'toename van productkwaliteit' of 'nieuwe marktkansen' in het vooruitzicht stelde. Hoewel de interne stimulus 'persoonlijke overtuiging van de mogelijke milieuwinst' dus geen garantie was voor implementatie van een optie, bleek deze wel een belangrijke motivatie om aan het IC EcoDesign project deel te nemen.

1.C: De deelnemers aan het IC EcoDesign project zullen ecodesign verbeteropties verwerpen die geassocieerd worden met de barrières 'onvoldoende complementariteit', 'geen interessante innovatierichting' of 'te geringe appropriabiliteit'. (Niet bevestigd)

Uit de 'capability theory' is afgeleid dat ecodesign verbeteropties aan minimaal drie eisen moeten voldoen willen ze een kans van slagen hebben. Ten eerste moeten ze complementair zijn aan (aansluiten bij) de bestaande producteisen. Ten tweede moet de verbeteroptie het bedrijf een interessante innovatierichting opleveren, indien er geen alternatieve technologische oplossingen voorhanden zijn. De derde eis is dat de optie moet leiden tot commercieel voordeel dat het bedrijf in kwestie zich zelf kan toeëigenen (appropriabiliteit).

De onderzoeksresultaten bevestigen hypothese 1.C slechts ten dele. 'Onvoldoende complementariteit' en 'onvoldoende appropriabiliteit' bleken slechts 'initiële' barrières te zijn. Het vóórkomen van deze barrières stond de implementatie van een ecodesign verbeteroptie niet geheel in de weg. Alleen indien er 'geen alternatieve oplossing voorhanden was' en de optie niet gezien werd als een 'interessante innovatierichting' bleek een zogenaamde 'no-go' barrière op te treden: de verbeteroptie had in dat geval geen enkele kans van slagen.
Echter, dit bleek niet de enige 'no-go' barrière te zijn. Het onderzoek gaf aan dat ook de volgende twee barrières getypeerd moeten worden als 'no-go' barrières: 1) twijfel aan de milieuwinst van een verbeteroptie en 2) het zich niet verantwoordelijk voelen voor implementatie van de optie.

2.A: Bedrijven die middels het IC EcoDesign project een goed ecodesign resultaat hebben behaald, zullen eveneens een groot ecodesign leefeffect hebben geboekt. (Bevestigd)

Hypothese 2.A werd bevestigd in dit onderzoek. Bivariate correlatieanalyses gaven aan dat de vijf indicatoren voor 'ecodesign resultaat' en de vijf indicatoren voor 'ecodesign leereffect' inderdaad gecorreleerd waren. Dit wijst erop dat bedrijven die hun producten milieukundig wisten te verbeteren waarschijnlijk ook in staat zijn om ecodesign zelfstandig toe te passen in toekomstige ontwikkelingsprojecten.

2.B: Bedrijven die ten gevolge van het IC EcoDesign project hoge scores hebben voor ecodesign resultaat en ecodesign leereffect, hebben een vergelijkbare ecodesign focus: zij vertonen overeenkomsten in de ecodesign strategieën die zij volgen. (Bevestigd)

De onderzoeksresultaten doen inderdaad vermoeden dat bedrijven die hun product milieukundig wisten te verbeteren en die in staat zijn om in de toekomst ecodesign zelfstandig toe te passen, ook qua ecodesign focus vergelijkbaar zijn. Via een clusteranalyse werden de bedrijven ingedeeld in acht zogenaamde 'ecodesign focus clusters'; de clustering was gebaseerd op het aantal en het ecodesign principe type van de verbeteropties die een bedrijf wilde gaan implementeren. Vervolgens bleken er aanzienlijke correlaties te bestaan tussen de variabele 'ecodesign focus cluster' en de tien indicatoren voor 'ecodesign resultaat' en voor 'ecodesign leereffect'. Dit impliceert dat bedrijven die bij ecodesign een overeenkomstige focus hebben, ook overeenkomsten vertonen in hun scores voor ecodesign leereffect en in de mate waarin zij hun producten milieukundig verbeterden.

3.A: Innovatieve bedrijven hebben een hogere ecodesign prestatie als gevolg van het IC EcoDesign project dan minder innovatieve bedrijven. (Bevestigd)

Het onderzoek bevestigt deze hypothese: hoe innovatiever het bedrijf, hoe hoger zijn ecodesign prestatie lijkt te zijn. De indicatoren voor innovativiteit waarop deze uitspraak berust zijn de mate waarin een bedrijf 'durft te experimenteren', 'actief zoekt naar nieuwe productideeën', 'investeert in R&D', 'producten ontwikkelt met unieke kenmerken' en 'innovatieve producten ontwikkelt'.
Deze conclusie bevestigt het idee dat ecodesign kan samengaan met meer gebruikelijke eisen bij productontwikkeling, zoals een hoge productkwaliteit, bedrijfszekerheid en gebruiksvriendelijkheid. Bedrijven die wat deze aspecten innovatief zijn, zijn waarschijnlijk ook 'eco-innovatief'.

3.B: Bedrijven met een groot milieubewustzijn hebben, ten gevolge van het IC EcoDesign project, een hogere ecodesign prestatie dan bedrijven met een gering milieubewustzijn. (Niet bevestigd)

De meeste indicatoren die gebruikt werden om het milieubewustzijn van een bedrijf te meten waren slechts zwak gecorreleerd met de tien ecodesign prestatie indicatoren. De enige uitzondering vormde de aanwezigheid van een milieuzorgsysteem. De MKB-bedrijven met een milieuzorgsysteem - hetzij informeel hetzij gecertificeerd - hadden een systematisch hogere ecodesign prestatie dan bedrijven zonder een dergelijk zorgsysteem. In het MKB zou daarom een milieuzorgsysteem een goede opstap kunnen vormen voor de toepassing van ecodesign (of vice versa).

3.C: Bedrijven met een positieve houding ten aanzien van ecodesign zullen een betere ecodesign prestatie hebben dan bedrijven die juist afwachtend of kritisch zijn. (Bevestigd)

De onderzoeksresultaten leiden tot de conclusie dat met name de houding van het management, de productontwikkelingsafdeling en de marketing-/verkoopafdeling ten opzichte van ecodesign van invloed is op de ecodesign prestaties van het bedrijf.

Overige conclusies inzake bedrijfskarakteristieken

- In sommige bedrijfstakken lijkt de ecodesign prestatie stelselmatig hoger te zijn dan in andere. De branches met over het algemeen de hoogste ecodesign prestatie zijn de electrotechnische industrie en de metaalproductenindustrie.
- Ook de kernactiviteit van een bedrijf lijkt samen te hangen met zijn ecodesign prestatie; bedrijven die productontwikkeling als één van hun kernactiviteiten beschouwen blijken een relatief hoge ecodesign prestatie te hebben, zowel qua concrete productverbeteringen als qua leereffect. Zogenaamde 'jobbers' (capaciteitsbedrijven) en groothandels voelen zich minder verantwoordelijk voor het milieukundig verbeteren van hun producten dan bedrijven die de specificaties voor hun producten vaststellen.
- Er is geen enkele indicatie dat, binnen de MKB-sector, grotere bedrijven een hogere ecodesign prestatie hebben dan kleinere. De bedrijfsgrootte, gemeten naar aantal medewerkers, blijkt niet gecorreleerd te zijn met de prestaties op het gebied van ecodesign.

4.A: Producten die bekend staan om hun milieubelasting lokken een hogere ecodesign prestatie uit dan producten waarvoor geen externe druk richting ecodesign bestaat. (Bevestigd)

Met behulp van verschillende indicatoren is gemeten hoe groot voor een bepaald product de externe druk om ecodesign toe te passen was. De onderzoeksresultaten bevestigden dat de ecodesign prestatie relatief hoog was voor producten waarvoor milieuwet- of regelgeving van toepassing is, waar klanten milieukritische vragen over stelden of die concurreren met producten die een beter milieuprofiel hebben. De resultaten bevestigden bovendien de eerdere conclusie dat van alle mogelijke externe factoren de milieueisen van industriële klanten en eindgebruikers de meest invloedrijke zijn.

4.B: Producten waarbij de toepassing van ecodesign gepaard gaat met commerciële voordelen leiden tot een relatief hoge ecodesign prestatie. (Bevestigd)

Het is niet verbazingwekkend dat de mate waarin een bedrijf ecodesign beschouwt als een commerciële kans van invloed is op zijn uiteindelijke ecodesign prestatie. Zo was de ecodesign prestatie relatief hoog indien een bedrijf ecodesign zag als een initiële investering die te zijner tijd wordt terugverdiend, als een middel om de productie- of logistieke efficiency te verhogen, om productie- of transportkosten te verlagen, om zijn marktaandeel te vergroten of om nieuwe markten mee te betreden. De oorzaak-gevolg relatie in deze is niet onderzocht.

Overige conclusies inzake productkarakteristieken

De analyse van het effect van een set overige productkarakteristieken op de ecodesign prestatie van een bedrijf leverde meer verrassende conclusies op. De ecodesign prestaties bleken relatief hoog te zijn indien een product wereldwijd wordt geëxporteerd, indien het bedrijf het product recentelijk op de markt had gebracht, indien het nog niet of slechts één maal een herontwerpslag had doorgemaakt, indien het in de 'groeifase' van zijn commerciële levenscyclus was of indien het een relatief korte levensduur had. Producten bestemd voor de industriële markt lijken een hogere ecodesign prestatie uit te lokken dan producten bestemd voor de consumenten- of institutionele markt.

5.A: Indien een respondent zich persoonlijk verantwoordelijk voelt voor het reduceren van milieubelasting is de ecodesign prestatie van zijn bedrijf relatief hoog. (Niet bevestigd)

De ecodesign prestatie van een bedrijf bleek slechts zwak gecorreleerd te zijn met de persoonlijke milieuovertuiging van de respondent - de vertegenwoordiger van het bedrijf in het IC EcoDesign project en in dit onderzoek. Dit bevestigt een eerdere conclusie dat het milieubesef van de bedrijfsleider weinig effect heeft op de mate waarin een bedrijf concrete milieuverbeteringen in zijn product heeft weten te realiseren. Deze factor bleek echter wel van invloed te zijn op de beslissing van het bedrijf om aan het IC EcoDesign project deel te nemen, dus om de toepassing van ecodesign überhaupt te overwegen.

5.B: Indien een respondent overtuigd is van het belang van ecodesign zal zijn bedrijf een hogere ecodesign prestatie boeken dan indien deze juist een kritische houding toont inzake ecodesign. (Bevestigd)

Zoals verwacht bestond er een correlatie tussen de mate waarin een respondent enthousiast was over ecodesign en de ecodesign prestatie van zijn bedrijf. De oorzaak-gevolg relatie is niet onderzocht: een positieve houding kan zowel de oorzaak als het gevolg zijn van het ecodesign resultaat dat het bedrijf boekte via het IC EcoDesign project. Het feit dat hypothese 5.A niet en hypothese 5.B wel is bevestigd lijkt paradoxaal. Dit is mogelijk te wijten aan de wijze waarop zij waren geoperationaliseerd.

Overige conclusies inzake respondentkarakteristieken

Verder toonde het onderzoek de ecodesign prestatie van bedrijven relatief hoog was indien de respondenten het IC EcoDesign project sterk waardeerden. Ook lijkt de positie van de respondent van invloed te zijn op de geboekte ecodesign prestatie: indien de respondent de bedrijfseigenaar/leider was bleek de ecodesign prestatie relatief hoog te zijn.

6: *Een ecodesign interventie leidt alleen tot een hoge ecodesign prestatie indien zij plaatsvindt op het moment dat het bedrijf de ambitie heeft om zijn product te innoveren. (Bevestigd)*

Het onderzoek bevestigt dat een ecodesign interventie de meeste kans van slagen heeft als ze plaatsvindt op het moment dat een bedrijf toch al van plan was het product te gaan herontwerpen. Dit bevestigt een eerdere conclusie dat de interventie het meest succesvol was bij producten die in de groeifase van hun commerciële levenscyclus waren. Het project was minder succesvol bij producten die nieuw waren voor de branche, die een verzadigde markt kenden of waarvan nieuwe, concurrerende versies op de markt waren verschenen.

Overige conclusies inzake interventiekarakteristieken.

Het onderzoek duidt erop dat de ecodesign prestatie van een bedrijf mede afhangt van de IC adviseur die de ecodesign interventie heeft gepleegd. Het is van belang om nader te gaan onderzoeken of dit afhangt van bijvoorbeeld zijn of haar milieudeskundigheid, adviesstijl of enthousiasme voor ecodesign en het IC EcoDesign project.

D. Aanbevelingen

Aanbevelingen voor verder onderzoek

De aanbevelingen ter verbetering van het ecodesign strategieënwiel zijn:

- *Ontwikkel ecodesign heuristieken*: Het lijkt zinvol en haalbaar om te bestuderen of men per productgroep een advies zou kunnen formuleren over welke ecodesign principes voor die productgroep vanuit milieuperspectief de meest zinvolle zijn. Deze heuristieken zouden kunnen worden afgeleid van de resultaten van reeds bestaande levenscyclusanalyses.
- *Bestudeer de synergie en conflicten tussen ecodesign principes*: In dit onderzoek is aandacht besteed aan de relaties tussen milieueisen en overige producteisen, maar niet aan de relaties tussen milieueisen onderling. Het is van belang de synergie en conflicten tussen milieueisen onderling en tussen milieueisen en overige producteisen verdergaand te identificeren en te beschrijven.

Aanbevelingen om meer te leren over verinnerlijking van ecodesign in een bedrijf:

- *Bestudeer ecodesign verinnerlijking:* Dit onderzoek liet zien dat bedrijven uiteenlopend scoorden inzake hun ecodesign leereffect. Echter, de vraag hoe deze verinnerlijking precies vorm kreeg bleef onbeantwoord. Zo is het duidelijk geworden dat sommige bedrijven een ecodesign checklist gebruiken, maar we weten niet hoe deze eruit ziet of hoe intensief hij wordt gebruikt. Nader onderzoek is vereist. Bestaande organisatietheorie (m.n. de vaardighedentheorie) en strategisch managementtheorie kunnen hierbij dienen als theoretisch kader.
- *Onderzoek naar de relatie tussen milieuzorg, ecodesign en productgerichte milieuzorg*: Dit onderzoek geeft aan dat een milieuzorgsysteem de aanzet kan geven tot ecodesign en vice versa. In Nederland is onlangs het programma opgestart ter stimulering van productgerichte milieuzorg. Het is een interessante onderzoeksvraag hoe deze drie systemen in de praktijk bij het MKB vorm krijgen, en of zij elkaar versterken of juist in de weg staan.

Aanbevelingen voor intermediaire organisaties die implementatie van ecodesign stimuleren

Het IC EcoDesign project mag 'effectief' worden genoemd. Dit blijkt uit de volgende onderzoeksresultaten:

- 247 (41%) van alle 596 ecodesign verbeteropties die de IC adviseurs aan de 77 onderzochte bedrijven adviseerden zijn al gerealiseerd of zullen binnen drie jaar gerealiseerd worden. Van deze 247 waren 183 opties al gerealiseerd (74% van 247 ofwel 31% van 596) ten tijde van het onderzoek.
- 60 van de 77 bedrijven hadden minstens één ecodesign optie gerealiseerd of zouden dit binnen drie jaar na het onderzoek doen.
- Eenderde van de ecodesign opties die worden gerealiseerd was geheel nieuw voor de betrokken bedrijven; eenderde hiervan waren door het bedrijf weer opgepakt dankzij het IC EcoDesign project; eenderde van deze opties zou gerealiseerd zijn ook indien het bedrijf niet had deelgenomen aan het IC EcoDesign project.
- In 21 van de 77 bestudeerde bedrijven heeft het IC EcoDesign project bijgedragen aan 'major product redesigns', ofwel ingrijpende productherontwerpen.

Op basis van het onderzoek zijn de volgende aanbevelingen geformuleerd.

- *Zorgvuldige selectie en training van de adviseurs*: De studie gaf aan dat de individuele invloed van de IC adviseurs groot was. Waarvan dit afhangt (kennisniveau, adviesstijl, enthousiasme voor ecodesign?) verdient nader onderzoek. Dit zou helpen de geconstateerde verschillen te verklaren en verduidelijken welk type adviseur het meest geschikt is om dit soort interventies te plegen.
- *Zorgvuldige selectie van bedrijven*: Het wordt aanbevolen bedrijven die deelnemen aan projecten als het IC EcoDesign project met zorg te selecteren. De voorkeur hebben bedrijven die productontwikkeling als een kernactiviteit zien, en bedrijven die hun product wensen te herontwerpen.
- *Pas ketenbenadering toe*: Dit onderzoek toonde aan dat een 'no-go' barrière ontstaat als een bedrijf het realiseren van een bepaalde optie niet als zijn verantwoordelijkheid ziet. Om dit te vermijden wordt aanbevolen ecodesign te stimuleren bij combinaties van bedrijven uit één keten ('partners in een bedrijfskolom'). Na overweging van alle ecodesign principes, waarbij de gehele productlevenscyclus wordt beschouwd, wijst men in overleg de diverse ecodesign taken toe aan die partner in de keten die zich het meest verantwoordelijk voelt voor de specifieke taak.
- *Adviseer overtuigende ecodesign verbeteropties*: Een andere 'no-go' barrière treedt op wanneer een bedrijf twijfelt aan de mogelijke milieuwinst van een ecodesign optie. De adviseur dient alleen die opties te noemen die werkelijk milieuwinst op gaan leveren. Eventuele twijfel zou besproken en weggenomen moeten worden door de mogelijke milieuwinst goed te beargumenteren.
- *Promoot 'benchmarking' (ofwel het vergelijken van de eigen ecodesign prestaties met die van concurrenten):* Een sterke stimulans voor ecodesign - hoewel niet vaak vóórkomend - bleek uit te gaan van de initiatieven van concurrenten op dit gebied. Daarom wordt het zinvol geacht bedrijven aan te zetten tot 'ecodesign benchmarking'. Dit geldt met name voor MKB-bedrijven, die in de regel hun concurrenten minder nauwlettend in de gaten (kunnen) houden dan grotere bedrijven.
- *Bied assistentie na de interventie*: Een ecodesign interventie staat of valt bij de 'follow-up support' die de betrokken adviseur biedt na de eigenlijke interventie. Aanbevolen wordt elk contact tussen bedrijf en adviseur te besluiten met een heldere vervolgafspraak.

Aanbevelingen voor het midden- en kleinbedrijf

- *Start een ecodesign proefproject*: Elk bedrijf dat bekend wil raken met ecodesign wordt aanbevolen te starten met een proefproject. In het project wordt ecodesign direct toegepast op een product dat ook vanwege andere redenen aan een herontwerp toe is. Zo wordt snel duidelijk wat de milieuknelpunten van het product zijn, welke informatie nodig is en welke bijkomende voordelen verbonden zijn aan ecodesign. Het onderzoek gaf aan dat ecodesign kan leiden tot kostenbesparingen en interessante innovatierichtingen. Geen enkel bedrijf kan deze kans laten liggen.
- *Vraag assistentie*: Met name MKB-bedrijven wordt aanbevolen aan te haken bij bestaande ecodesign stimulatieprogramma's. Veel MKB-bedrijven, die erg druk zijn met hun dagelijkse werkzaamheden, zijn gebaat bij een kort en bedrijfsspecifiek advies dat vervolgens in stappen geïmplementeerd kan worden.
- *Ecodesign verinnerlijking*: Na een ecodesign proefproject moet het geleerde 'verinnerlijkt' worden. MKB-bedrijven wordt aanbevolen een ecodesign checklist op te stellen met die ecodesign principes die bij elk productontwikkelingsproces overwogen dienen te worden. Deze checklist dient aan te

sluiten op bestaande productontwikkelingsprocedures. Verder is het zinvol om een 'meetbare' ecodesign doelstelling te schrijven waarin staat wat het bedrijf over ca. drie jaar wil hebben bereikt.

- *Ontwikkel een milieuplan*: Ook MKB-bedrijven wordt aanbevolen een milieuplan op te stellen waarin zij aangeven welke milieu-initiatieven ze de komende jaren willen gaan nemen. Dit plan is niet bedoeld voor de buitenwereld maar voor intern gebruik. Het biedt overzicht, een structuur en een referentie. De ISO 14.001 norm voor certificatie van milieuzorgsystemen zou kunnen dienen als raamwerk, ook als een bedrijf zich niet volgens deze norm wil laten certificeren.
- *Streef naar horizontale en verticale samenwerking:* Met name voor het MKB is samenwerking, ook op het gebied van ecodesign, van belang. Door samen te werken in de branche kunnen toeleveranciers gemotiveerd worden eco-efficiënte materialen of technologieën te ontwikkelen. Ook kan men als branche gezamenlijk voorstellen ontwikkelen om toekomstige milieuwet- en regelgeving te beïnvloeden. Samenwerking in de keten (of bedrijfskolom) is zinnig omdat de ecodesign taken dan in overleg toegewezen kunnen worden aan de partijen die daarvoor het meest geschikt zijn. 'Ketenpartners' kunnen elkaar via afzetgaranties motiveren investeringen te plegen.

Aanbevelingen voor industrieel ontwerpers

- *Begin met de meest succesvolle ecodesign principes*: Uit dit onderzoek bleek dat tien van de 33 onderscheiden ecodesign principes duidelijk meer succesvol waren dan de overige (zie Figuur 5). Het verdient aanbeveling met deze tien meest succesvolle ecodesign principes te starten, mits zij relevant zijn. Zodoende wordt een draagvlak voor ecodesign geschapen, waardoor het in een later stadium mogelijk is ook minder voor de hand liggende ecodesign principes toe te passen.
- *Betrek het management bij ecodesign*: In dit onderzoek zijn betere ecodesign resultaten geboekt wanneer de bedrijfsleider zelf aan het IC EcoDesign project deelnam. Dit bevestigt het vermoeden dat steun vanuit het management voor ecodesign een randvoorwaarde vormt. Het is belangrijk om in overleg de ecodesign doelstelling te bepalen. De steun is verder nodig om extra capaciteit en budget te bemachtigen om een ecodesign project uit te voeren.
- *Spreek de taal van het bedrijf*: Om beslissers te overtuigen van het nut van een ecodesign verbeteroptie, en om deze personen argumenten te geven om weer anderen te overtuigen, is het noodzakelijk het nut van de optie weer te geven in 'facts and figures'.
- *Benut stimuli, bespreek barrières*: Figuur 5 vat samen wat volgens dit onderzoek de meest invloedrijke stimuli en barrières voor ecodesign zijn. De ontwerper wordt aanbevolen per ecodesign verbeter-optie te overwegen welke stimuli en barrières kunnen optreden. De stimuli kan hij gebruiken als argumenten om een optie uit te voeren. Eventuele barrières zou hij ter discussie moeten stellen. Zijn deze inderdaad onoverkomelijk dan is het zinvoller de aandacht te richten op andere ecodesign opties.
- *Inventariseer ontwikkelingen bij toeleveranciers*: Ook industrieel ontwerpers wordt aanbevolen om externe hulp in te roepen bij ecodesign. De ontwerper dient met name de ontwikkelingen bij toeleveranciers goed te volgen en hen, zo mogelijk, bij ecodesign activiteiten te betrekken.
- *Gebruik 'ecodesign benchmarking'*: Ook de ecodesign initiatieven van concurrenten dient de ontwerper nauwlettend te volgen. Indien de concurrent claimt dat zijn product 'groener' is, is de ontwerper gewaarschuwd. Als de concurrent achter loopt, is de ontwerper wellicht een 'unique selling point' op het spoor.
- *Word lid van O2 Nederland*: Industrieel ontwerpers die hun kennis op het gebied van ecodesign willen vergroten, die regelmatig inspiratie willen opdoen en die een ecodesign netwerk willen opbouwen wordt aanbevolen lid te worden van de vereniging O2 Nederland (tel. 010-411 81 02).

Aanbevelingen voor de ontwikkelaars van overheidsbeleid inzake ecodesign implementatie

- *Voortzetting van stimulatieprogramma's*: De overheid wordt aanbevolen programma's als het IC EcoDesign project voort te zetten zolang ecodesign niet voldoende wordt toegepast. Het onderzoek gaf aan dat het IC EcoDesign programma effectief was, in de zin dat het de ecodesign bewust-wording in het MKB deed toenemen, alsook het aantal concrete initiatieven op dit terrein.
- *Voortzetting van financiële ondersteuning*: Overheidssteun kan helpen het MKB te motiveren te investeren in ecodesign. Blijkens dit onderzoek maken maar weinig MKB-bedrijven daadwerkelijk gebruik van de bestaande MPO Kredietregeling. De overheid wordt aanbevolen dergelijke regelingen nog beter toegankelijk te maken, en deze met name te richten op het MKB.

- *Verdere promotie ecodesign op nationaal niveau*: De studie gaf aan dat ecodesign gepaard kan gaan met kostenreducties en nieuwe innovatiemogelijkheden, vooral voor eindproducten zoals bestudeerd in dit proefschrift. De overheid wordt aanbevolen deze boodschap sterker, en op nationaal niveau, uit te dragen.
- *Creeër sterke en consistente externe stimuli voor ecodesign*: Uit dit onderzoek bleek dat MKB-bedrijven momenteel met name die ecodesign opties implementeren die gepaard gaan met een commercieel voordeel. Hoe nu bedrijven te motiveren ook ecodesign opties te realiseren met een grotere milieuwinst, maar met minder direct commercieel voordeel? Dit zou kunnen door de bedrijven te beïnvloeden via sterkere en meer diverse externe stimuli. Zo zou de vraag naar eco-efficiënte producten moeten toenemen, opdat de bedrijven hierin met meer vertrouwen investeren. De studie geeft diverse mogelijkheden om deze 'market pull' te intensiveren. De overheid kan consumentenorganisaties zoals de ConsumentenBond stimuleren (eventueel via financiële ondersteuning) nog vaker producten ook op hun milieuprofiel te beoordelen. Het blijkt dat hun testen een sterke invloed uitoefenen op met name producentengedrag.
  Speciaal voor MKB-bedrijven die reactief zijn inzake ecodesign wordt de overheid aanbevolen het aantal milieutaakstellingen uit te breiden. Deze taakstellingen, zoals het verpakkingsconvenant en de komende terugnameverplichting zetten dit type bedrijven aan het werk. Direct, doordat zij anders een boete riskeren, of indirect, omdat grotere partners in hun bedrijfskolom hen hierop aanspreken. Omdat deze taakstellingen branchegericht zijn gaat ook een externe stimulans uit van de branche-organisaties. Zij maken de afspraken met de overheid, en stimuleren hun leden deze afspraken ook na te komen. Tot slot wordt aanbevolen ook milieuorganisaties en financiële instanties zoals verzekeraars te stimuleren om milieueisen te ventileren richting het MKB.
- *Pas een branchegerichte benadering toe:* Het onderzoek toonde aan dat sommige branches (met name de electrotechnische en de metaalproductenindustrie) op het gebied van ecodesign meer presteerden dan andere. Verder bleek dat brancheorganisaties het ecodesign gedrag van bedrijven beïnvloeden. Dit leidt tot de aanbeveling de milieutaakstellingen ook in de toekomst branchespecifiek te formuleren.
- *Stimuleer productgerichte milieuzorg (PMZ):* De PMZ-regeling stimuleert bedrijven ecodesign in hun management procedures te verankeren. Dit onderzoek gaf aan dat een milieuzorgsysteem (MZS) bij een bedrijf de aanleiding kan zijn voor ecodesign en vice versa. Ook wordt het belang van verinnerlijking van ecodesign benadrukt. Daarom wordt de overheid aanbevolen de PMZ-regeling door te zetten. In de huidige vorm lijkt deze voor het MKB ongeschikt. Daarom zou voor MKB-bedrijven een variant moeten worden ontwikkeld die toegespitst is op hun mogelijkheden en wensen.
- *Van ecoredesign naar ecodesign*: De ecodesign resultaten van de bedrijven die deelnamen aan het IC EcoDesign project kunnen getypeerd worden als 'ecoredesigns'. Het is zinvol, vanuit milieu- én vanuit ondernemingsperspectief, in de nabije toekomst een stap verder te gaan door bedrijven te stimuleren tot de ontwikkeling van werkelijke 'ecodesigns' of zelfs 'sustainable product designs'. Pas wanneer men bedrijven, op basis van de bestaande ervaring met ecoredesign interventies, aanzet tot het overwegen van zogenaamde 'factor 4 milieu-innovaties' wordt het innovatiepotentieel van ecodesign ten volle benut.

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Appendix A Interview questionnaire

Vragenlijst directe milieuwinst	**Vragen per optie**

Bedrijf:..**Bedrijfsnummer:** ....

ja/nee

1 2	**1.**	Bent u doorgegaan met uitvoering van minstens één optie?
1 2	**2.**	Bent u, los van de verbeteropties die in het adviesrapport staan, nog andere gaan uitwerken? (zo ja, dan worden ook voor deze opties bladen ingevuld)
1 2	**3.**	Verwacht u in de toekomst op enigerlei wijze door te gaan met het ecodesign advies?

Indien op één of meer vragen JA wordt geantwoord, dan is of wordt er actie ondernomen op het gebied van ecodesign en kan er sprake zijn van direkte milieuwinst. Om te weten in welke opties het bedrijf geïnteresseerd is en waarom, worden de volgende vragen gesteld.

Optienummer: ..... *van* .....
Optietype: .....
Omschrijving van de optie: ....

6. In hoeverre heeft u deze optie weten te realiseren?
0= er wordt nu niet aan gewerkt, ook in de toekomst geen belangstelling hiervoor
3= er wordt nu niet aan gewerkt, binnen 2 jaar hebben we er wel belangstelling voor
4= deze optie is in onderzoek/ontwikkeling; realisatie verwacht binnen 3 jaar
5= deze optie is in onderzoek/ontwikkeling; realisatie verwacht binnen 1 jaar
6= er is wel aan gewerkt: deze optie is reeds of wordt zéér binnenkort gerealiseerd

7. In welke mate was u al bezig met deze optie vóórdat de scan werd uitgevoerd?
1 = au = we zouden de optie zowiezo al implementeren
2 = st = het idee, dat bij ons al was opgekomen, werd door het project versterkt, kwam tot leven
3 = ic = het idee was geleverd door het IC; bij ons was het nog nooit opgekomen

Indien vraag 6 wordt beantwoord door <u>3, 4, 5 of 6</u> worden de volgende vragen gesteld:

8. Tot welke concrete produktverbetering heeft deze optie geleid?..

....

9. Waarom vindt u deze optie zo interessant?..

....

10. Hoe belangrijk was realisatie van deze optie voor u? weinig belang 1 2 3 4 5 zeer veel belang

11.		**Externe factoren: Deze optie wordt gestimuleerd door....**
1 2 3 4 5	a.	Overheidsregulering
1 2 3 4 5	b.	Activiteiten vanuit uw brancheorganisatie
1 2 3 4 5	c.	Eisen gesteld door uw afnemers
1 2 3 4 5	d.	Druk van een milieu-actiegroep
1 2 3 4 5	e.	Ontwikkelingen bij uw toeleveranciers
1 2 3 4 5	f.	Activiteiten van uw concurrenten
1 2 3 4 5	h.	Invloed van een andere externe factor Namelijk ....

12.	**Interne factoren als stimulans:**	
1 2 3 4 5	a.	De optie levert veel milieuwinst op
1 2 3 4 5	b.	Deze optie levert een kostenbesparing op
1 2 3 4 5	c.	Deze optie kan een sterke imagoverbetering van ons bedrijf betekenen
1 2 3 4 5	d.	Deze optie geeft aan dit produkt nieuwe marktkansen
1 2 3 4 5	e.	Deze optie betekent een verhoging van de produktkwaliteit
1 2 3 4 5	f.	Invloed van ander bedrijfseconomisch voordeel, Namelijk: ....
1 2 3 4 5	g.	De optie sluit goed aan bij de huidige produkteisen Met name:..
1 2 3 4 5	h.	De optie vormt een conflict met bepaalde produkteisen De eis waar een conflict mee ontstaat is: ....
1 2 3 4 5	i.	De optie vormt voor ons een interessante technologische innovatierichting

Als vraag 6 beantwoord is met 0, dan volgen de volgende vragen:

13. De optie is voor uw bedrijf kennelijk niet interessant genoeg. Wat is de belangrijkste reden waarom de optie voor uw bedrijf niet interessant is?...

....

14. Wat zou er BUITEN uw bedrijf moeten gebeuren wil u wèl verder gaan met deze optie?

....

15. Wat zou er BINNEN uw bedrijf moeten gebeuren wil u wèl verder gaan met deze optie?

....

16.	**Interne factoren als barrières:**	
1 2 3 4 5	a	De optie ligt buiten de invloedsfeer en verantwoordelijkheid van ons bedrijf
1 2 3 4 5	b.	De optie levert ons bedrijf geen bedrijfseconomisch voordeel
1 2 3 4 5	c.	De optie vormt een conflict met uw huidige produkteisen De eis waar een conflict mee ontstaat is: ....
1 2 3 4 5	d.	De optie betekent voor ons bedrijf geen technologische innovatieve uitdaging
1 2 3 4 5	e.	De investeringsruimte, nodig voor deze optie, is onvoldoende
1 2 3 4 5	f.	We hebben voldoend capaciteit in manuren om deze optie te realiseren
1 2 3 4 5	g.	We beschikken niet over voldoende kennis voor realisatie van deze optie

Per optie worden de volgende gegevens in de optiematrix ingevoerd.	codekaart
Realisatiegraad	0 1 2 3 4 5 6 7
0= er is niet aan gewerkt, ook in de toekomst is er geen belangstelling voor 1= er is aan gewerkt; realisatie wordt echter niet doorgezet 2= er is nog niet aan gewerkt, binnen 2 jaar hebben we er wel belangstelling voor 3= er wordt aan gewerkt; realisatie is nog onzeker 4= er wordt aan gewerkt; realisatie verwacht binnen 1 jaar (prototype fase) 5= er wordt aan gewerkt; realisatie verwacht binnen 3 jaar 6= er is aan gewerkt: deze optie is reeds of wordt zéér binnenkort gerealiseerd 7= deze optie heeft onze continue aandacht; geen extra aandacht aan besteed	
Toegevoegde waarde ICED	1 2 3
1 = au = we zouden de optie zowiezo al implementeren 2 = st = het idee, dat bij ons al was opgekomen, werd door het project versterkt 3 = ic = het idee was geleverd door het IC; bij ons was het nog nooit opgekomen	

Externe stimulus	**1 2 3 4 5 6 7**
1= overheidsregulering 2= activiteiten vanuit uw brancheorganisatie 3= eisen gesteld door uw afnemers 4= druk van een milieu-actiegroep 5= ontwikkelingen bij uw toeleveranciers 6= activiteiten van uw concurrenten 7= invloed van een andere externe factor	
Interne stimulus	**1 2 3 4 5 6 7 8 9**
1= de optie levert milieuwinst op 2= de optie levert een kostenbesparing op 3= de optie kan een imagoverbetering van ons bedrijf betekenen 4= de optie geeft aan dit produkt nieuwe marktkansen 5= de optie betekent een verhoging van de produktkwaliteit 6= de optie versterkt andere produkteisen 7= de optie levert een ander bedrijfseconomisch voordeel 8= de optie vormt voor ons een interessante technologische innovatierichting 9= anders	

Barrière voor de optie	**1 2 3 4 5 6 7 8 9 10 11 12**
1= de milieuwinst van deze optie vinden wij onvoldoende aannemelijk 2= de optie ligt buiten de verantwoordelijkheid van ons bedrijf 3= de optie is afhankelijk van de stand der techniek; er is nog geen oplossing voor handen 4= de optie wordt pas relevant als er dienaangaande wetgeving komt 5= de optie wordt pas relevant als onze klanten er ons om vragen 6= de optie levert ons bedrijf geen bedrijfseconomisch voordeel 7= de optie vormt een conflict met de huidige produkteisen 8= de optie betekent voor ons bedrijf geen technologische innovatieve uitdaging 9= de investeringsruimte, nodig voor deze optie, is onvoldoende 10= we hebben nu onvoldoende capaciteit in manuren om deze optie te realiseren 11= we beschikken over onvoldoende kennis voor realisatie van deze optie 12= anders	

Appendix B Postal questionnaire

Blok I	**Vragen over kenmerken van uw produkt**			
Hieronder volgt een aantal vragen over het produkt dat gekozen is voor doorlichting tijdens de scan.				
1.	**Welk produkt was geselecteerd voor de scan?** *De naam van dit produkt zal in geen enkele rapportage verschijnen.*	....		1
2.	**Wat is het afzetgebied van het produkt?**	• met name Nederland • met name Nederland en Duitsland • West Europa • geheel Europa • met name de V.S. • wereldwijd • anders, namelijk:	1 2 3 4 5 6 7	2 3
3.	**Wat is de jaarlijkse seriegrootte van het produkt?**	seriegrootte:	.....	4
4.	**In welk jaar is het geselecteerde produkt op de markt geïntroduceerd?**	jaar van marktintroductie:	.....	5
5.	**Hoeveel maal is dit produkt sindsdien ingrijpend herontworpen (afgezien van kleine produktverbeteringen)?**	aantal herontwerpslagen:	.....	6
6.	**Wanneer is het produkt voor het laatst ingrijpend herontworpen?** *Geef a.u.b. uw schatting in maanden.*	aantal maanden geleden:	.....	7
7.	**Wat waren, op het moment van de scan, uw ontwikkelingsplannen ten aanzien van het geselecteerde produkt?** *Indien gewenst kunt u 2 antwoordcijfers omcirkelen.*	• dit produkt was juist toe aan een flinke herontwerpslag • een herontwerptraject voor dit produkt was in volle gang • een herontworperptraject hiervoor was juist afgesloten • dit produkt was zojuist nieuw ontwikkeld • dit produkt was niet toe aan enige produktontwikkeling • u keek uit naar een geheel nieuw produktconcept; wijziging van het geselecteerde produkt was ongewenst • anders, namelijk:	1 2 3 4 5 6 7	8 9 10
8.	**In welke fase van de produktlevenscyclus bevond het geselecteerde produkt zich tijdens de scan?**	• introductie: het produkt was juist op de markt gebracht • groei: het marktaandeel was groeiende • volwassenheid: het marktaandeel stagneerde • verval: het marktaandeel was aan het zakken	1 2 3 4	11
9.	**Hoe lang gebruiken afnemers het produkt gemiddeld?** *Geef a.u.b. uw schatting in jaren.*	geschatte gebruiksduur in jaren:	.....	12
10.	**Op welk type markt wordt het produkt voornamelijk afgezet?**	• consumentenmarkt • industriële markt • overheid	1 2 3	13
11.	**Waarom is juist dit produkt geselecteerd voor de scan?** *Indien gewenst kunt u 3 antwoordcijfers omcirkelen.*	• dit produkt is ons enige produkt • de milieuproblematiek rond dit produkt leek redelijk overzichtelijk • rond dit produkt was milieu-wetgeving in ontwikkeling • dit produkt was aan een herontwerpslag toe • we verwachten marktkansen door juist dit produkt milieukundig te verbeteren • anders, namelijk:	1 2 3 4 5 6	14 15 16 17
12.	**Hoeveel verschillende produkten heeft uw bedrijf op dit moment in ontwikkeling?**	aantal produkten in ontwikkeling:	.....	18

	Blok 2 Vragen over kenmerken van uw bedrijf		
	Om te kunnen onderzoeken in hoeverre het resultaat van het IC Ecodesign-project samenhangt met het type bedrijf waar het project heeft plaatsgevonden en het soort produkt dat daarbij centraal stond, wordt u verzocht de volgende set vragen in te vullen.		
13.	**Hoeveel medewerkers telt uw bedrijf, inclusief uzelf?**	totaal aantal medewerkers:	.....
14.	**Hoeveel produktontwikkelaars heeft uw bedrijf in dienst?**	aantal produktontwikkelaars:	.....
15.	**Wat is de SBI-code van uw bedrijf?** *Omcirkel a.u.b. het codenummer dat behoort bij uw bedrijfsklasse*	• textielindustrie • kledingindustrie • lederwarenindustrie • hout- en meubelindustrie • papier- en papierwarenindustrie • rubber- en kunststofverwerkende industrie • metaalproduktenindustrie • machine-industrie • elektrotechnische industrie • transportmiddelen industrie • instrumenten- en optische industrie • overige industrie	22 23 24 25 26 31 34 35 36 37 38 39
16.	**Gebruikt u schriftelijke procedures zoals checklists bij uw produktontwikkeling?**	• ja • nee • niet relevant	1 2 9
17.	**Stelt u altijd zelf de produktspecificaties op voor de produkten die u verkoopt?**	• ja • nee • niet relevant	1 2 9
18.	**Levert u een produkt dat direkt geleverd kan worden aan de eindgebruiker (een 'eindprodukt')?**	• ja • nee	1 2
19.	**Welk type produkten levert uw bedrijf?** *Geef hiervan a.u.b. een korte beschrijving.*		
20.	**Wat is de kernactiviteit van uw bedrijf?**	• ontwikkeling, produktie, assemblage en verkoop • ontwikkeling, assemblage en verkoop • ontwikkeling en verkoop • voornamelijk verkoop • anders, namelijk:	1 2 3 4 5

21.	Wilt u aangeven in hoeverre u het al dan niet eens bent met de volgende uitspraken?	zeer mee oneens	oneens	neutraal	eens	zeer mee eens
	a. Ons bedijf durft te experimenteren bij het introduceren van nieuwe produkten op de markt	1	2	3	4	5
	b. Ons bedrijf is voortdurend op zoek naar nieuwe produktideeën	1	2	3	4	5
	c. Ons bedrijf besteedt veel aandacht aan onderzoek en ontwikkeling	1	2	3	4	5
	d. In ons bedrijf wordt creativiteit gestimuleerd door speciaal hiervoor tijd en middelen ter beschikking te stellen	1	2	3	4	5
	e. Bij het lanceren van nieuwe produkten neemt ons bedrijf risico	1	2	3	4	5
	f. In ons bedrijf worden medewerkers aangemoedigd om zelf initiatieven te nemen	1	2	3	4	5
	g. Vergeleken met concurrerende produkten, bieden onze nieuwe produkten unieke mogelijkheden ('features') aan de afnemers.	1	2	3	4	5
	h. Onze produkten zijn kwalitatief hoogwaardiger dan die van onze belangrijkste concurrenten	1	2	3	4	5
	i. Ons bedrijf is een typische volger: wij leveren vooral 'me too' produkten	1	2	3	4	5
	j. Omdat we te maken hebben met een sterke concurrentiedruk, concurreert ons bedrijf voornamelijk op prijs	1	2	3	4	5
	k. Onze nieuwe produkten zijn sterk innovatief: ze zijn de eerste in hun soort die in onze bedrijfstak op de markt gebracht zijn.	1	2	3	4	5
	l. Onze produkten zijn technisch zeer geavanceerd	1	2	3	4	5
	m. In onze produkten worden altijd de nieuwste technologieën toegepast	1	2	3	4	5
	n. Wij weten wat afnemers van onze produkten verlangen	1	2	3	4	5

22.	**Hoe innovatief is uw bedrijf vergeleken met uw belangrijkste concurrenten?**	veel minder	minder	gelijk	meer	veel meer	
		1	2	3	4	5	42
23.	**Sinds welk jaar levert uw bedrijf produkten die uw bedrijf zelf ontwikkeld heeft?**				sinds het jaar:	.....	43
24	**Hoeveel verschillende produkten heeft u op dit moment in uw produktassortiment (produktvarianten niet inbegrepen)?**				aantal te leveren produkten:	.....	44
25.	**Hoeveel van deze produkten zijn in de afgelopen 5 jaar (sinds 1991) : a. op enkele aspecten verbeterd?**				aantal licht verbeterde produkten:	.....	45
	b. ingrijpend herontworpen?				aantal herontworpen produkten:	.....	46
	c. geheel nieuw ontwikkeld?				aantal geheel nieuwe produkten:	.....	47
26.	**Wat is het percentage van de huidige omzet dat te danken is aan de produkten die uw bedrijf de laatste 5 jaar (dus vanaf 1991) op de markt heeft gebracht? Tel hierbij alleen de produkten mee die genoemd zijn bij de vragen 25b en 25c.** *Omcrikel a.u.b. het percentage dat hierbij het dichtst in de buurt komt.*				10% 20% 30% 40% 50%	60% 70% 80% 90% 100%	48
27.	**Wat is het percentage van de huidige winst dat te danken is aan de produkten die uw bedrijf de laatste 5 jaar (dus vanaf 1991) op de markt heeft gebracht? Tel hierbij alleen de produkten mee die genoemd zijn bij de vragen 25b en 25c.** *Omcirkel a.u.b. het percentage dat hierbij het dichtst in de buurt komt.*				10% 20% 30% 40% 50%	60% 70% 80% 90% 100%	49
28.	**Beschikt uw bedrijf over een kwaliteitszorgsysteem?**				• ja, ISO-gecertificeerd • ja, maar niet ISO-gecertificeerd • nee	1 2 3	50

Blok 3 Vragen over de factor milieu in uw bedrijfsvoering

De meeste bedrijven waren, vóór er sprake was van milieugerichte produktontwikkeling, al rekening gaan houden met de factor milieu in hun bedrijfsvoering. Deze milieu-inspanning was met name gericht op het beheer van milieuvergunningen, bedrijfsinterne milieuzorg, schoner produceren en afvalmanagement. Over dit type milieu-inspanning volgt nu een set vragen.

29.	**Beschikt uw bedrijf over een milieuzorgsysteem?**				• ja • ten dele (partieel systeem) • nee	1 2 3	51
30.	**Nam uw bedrijf deel aan het IC-project Schoner Produceren?**				• ja • nee • onbekend	1 2 3	52
31.	**Heeft uw bedrijf een milieu-convenant ondertekend?**				• ja • nee • onbekend	1 2 3	53
32.	**Hoe groot schat u de milieu-inspanningen van uw bedrijf sinds 1 januari 1991, vergeleken met de milieu-inspanning van uw concurrenten?**	veel kleiner	kleiner	gelijk	groter	veel groter	
		1	2	3	4	5	54
33.	**Hoe vaak heeft uw bedrijf sinds 1991 een systematische milieu-vergelijking met concurrenten uitgevoerd ?**				aantal malen:	.....	55
34.	**Bij wie binnen uw bedrijf liggen de uitvoerende milieutaken (o.a. beheer van milieu-vergunningen) op dit moment?**				• bij niemand in het bijzonder • bij de milieumanager • bij de kwaliteitszorgmanager • bij de afdeling produktie • bij het bedrijfsmanagement • bij een andere medewerker	1 2 3 4 5 6	56

Blok 4 Vragen over milieugerichte produktontwikkeling bij uw bedrijf

Bij het IC Ecodesign-project staat het begrip ecodesign, oftewel milieugerichte produktontwikkeling (MPO) centraal. De volgende set vragen gaat over de relatie tussen MPO en uw bedrijfsvoering.

35.	Onderstaand volgt een aantal stellingen over MPO. Wilt u aangeven in hoeverre u het met deze stellingen al dan niet eens bent?	zeer mee oneens	oneens	neutraal	eens	zeer mee eens	
	a. MPO is voor ons bedrijf een kans om financieel voordeel te behalen.	1	2	3	4	5	57

	Vervolg van vraag 35	zeer mee oneens	oneens	neutraal	eens	zeer mee eens
	b. Ons bedrijf kan MPO gebruiken als verkoopargument in de marketing	1	2	3	4	5
	c. Wetgeving maakt MPO voor ons bedrijf noodzakelijk	1	2	3	4	5
	d. Voor ons bedrijf levert MPO kosten noch baten op	1	2	3	4	5
	e. Voor ons bedrijf is MPO een kostenpost die zich op de lange termijn terugverdient.	1	2	3	4	5
	f. Voor ons bedrijf is MPO een kostenpost die zich op de lange termijn niet terugverdient.	1	2	3	4	5
36.	**Had uw bedrijf reeds vóór de scan ervaring op het gebied van MPO opgedaan?**	geheel niet	nauwelijks	enigszins	beperkte mate	sterke mate
		1	2	3	4	5
	Zo ja, wilt u deze MPO-ervaring hieronder kort beschrijven?					
37.	**Wat is de houding ten opzichte van milieugerichte produktontwikkeling van de volgende personen in uw bedrijf?**	zeer afwijzend	afwijzend	neutraal	betrokken	zeer betrokken
	a. het bedrijfsmanagement	1	2	3	4	5
	b. de afdeling produktontwikkeling	1	2	3	4	5
	c. de afdeling marketing en/of verkoop	1	2	3	4	5
	d. de afdeling milieuzaken	1	2	3	4	5
	e. de afdeling kwaliteitszorg	1	2	3	4	5
	f. de afdeling inkoop	1	2	3	4	5
	g. de afdeling produktie	1	2	3	4	5
38.	**Wie heeft MPO als eerste bij uw bedrijf op de agenda gezet?**	• uw IC-adviseur • uzelf • één van uw medewerkers • één van uw afnemers • iemand anders				1 2 3 4 5
39.	**In welke mate hebben de volgende argumenten meegespeeld bij uw beslissing om aan het IC Ecodesign-project deel te nemen?**	geheel niet	nauwelijks	enigszins	beperkte mate	sterke mate
	a. U was op zoek naar een milieuvriendelijk alternatief voor een materiaal of onderdeel	1	2	3	4	5
	b. U nam deel omdat u zich persoonlijk betrokken voelt bij 'het milieu'	1	2	3	4	5
	c. Uw bedrijf had zich expliciet ten doel gesteld het milieu-profiel van de produkten te verbeteren	1	2	3	4	5
	d. U wilde weten hoe groot de milieubelasting van uw produkt ten opzichte van concurrerende produkten is	1	2	3	4	5
	e. U wilde ingelicht worden over wetgeving op het gebied van MPO	1	2	3	4	5
	f. U ziet MPO als een belangrijk aspect van produktinnovatie	1	2	3	4	5
	g. U ziet een lage milieubelasting als onderdeel van produktkwaliteit	1	2	3	4	5
	h. U ziet MPO als middel om de efficiency in uw bedrijfsvoering te verhogen	1	2	3	4	5
	i. U wilt op alle gebieden bijblijven, dus ook op het gebied van MPO	1	2	3	4	5
	j. Afnemers stellen steeds hogere milieu-eisen aan onze produkten	1	2	3	4	5
	k. U wilde weten of uw produkt het risico liep een negatief milieu-imago te krijgen	1	2	3	4	5
	l. U wilde uw achterstand op het gebied van MPO ten opzichte van uw concurrent inlopen	1	2	3	4	5
	m. U wilde een 'second opinion' om hiermee uw 'groene marketing-claim' te kunnen onderbouwen	1	2	3	4	5
	n. Aan het project waren subsidiemogelijkheden verbonden	1	2	3	4	5
	o. U wilde uw IC-adviseur een plezier doen door deel te nemen	1	2	3	4	5
	p. Vanwege een andere reden **Namelijk:**	1	2	3	4	5

Blok 5 Vragen over milieugerichte produktontwikkeling en uw omgeving

Niet alle bedrijven worden vanuit hun omgeving even sterk gemotiveerd om aan milieugerichte produktontwikkeling te doen. Onderstaand volgt een aantal vragen waarmee de omgeving van uw bedrijf beschreven kan worden.

40.	**Was u al bekend met uw IC-adviseur vóórdat er sprake was van het IC Ecodesign-project?**	• ja • nee	1 2	90
41.	**Heeft u nà de scan nog regelmatig over het MPO-advies gesproken met uw IC-adviseur?**	• ja • nee	1 2	91
42.	**Is uw bedrijf aangesloten bij één of meer branche-organisaties?**	• ja • nee	1 2	92
43.	**Zo ja, wilt u dan hieronder aangeven bij welke branche-organisatie(s) uw bedrijf is aangesloten?**			93
44.	**Via een vrijwaringsverklaring garandeert een leverancier dat zijn produkt bepaalde stoffen niet bevat. Heeft uw bedrijf voor één of meer afnemers een zogenaamde 'vrijwaringsverklaring' ondertekend?**	• ja • nee • onbekend	1 2 3	94
45.	**Heeft uw bedrijf aan één of meer afnemers de garantie gegeven uw produkten na gebruik terug te nemen en te (her)verwerken?**	• ja • nee • onbekend	1 2 3	95
46.	**Heeft uw branche een milieu-convenant met de overheid afgesloten?**	• ja • nee • onbekend	1 2 3	96
47.	**Is uw bedrijf ooit doelwit geweest van een actie van een milieu-organisatie?**	• ja • nee • onbekend	1 2 3	97
48.	**Is uw branche ooit doelwit geweest van een actie van een milieu-organisatie?**	• ja • nee • onbekend	1 2 3	98

49.	**Hoe beoordeelt u de houding inzake MPO van de volgende partijen?**	zeer afwijzend	afwijzend	neutraal	betrokken	zeer betrokken	
	a. Van bovengenoemde branche-organisatie(s)	1	2	3	4	5	99
	b. Van de Nederlandse overheid	1	2	3	4	5	100
	c. Van uw direkte afnemers	1	2	3	4	5	101
	d. Van de eindgebruikers van uw produkt	1	2	3	4	5	102
	e. Van de tussenhandel, zoals uw dealers	1	2	3	4	5	103
	f. Van uw leveranciers	1	2	3	4	5	104
	g. Van uw concurrenten	1	2	3	4	5	105

50.	**In welke mate wordt u door de volgende factoren gestimuleerd om MPO toe te passen bij uw produktontwikkeling?**	geheel niet	nauwelijks	enigszins	beperkte mate	sterke mate	
	a. Door uw branche	1	2	3	4	5	106
	b. Door overheidsregelingen	1	2	3	4	5	107
	c. Door uw direkte afnemers	1	2	3	4	5	108
	d. Door eindgebruikers	1	2	3	4	5	109
	e. Door de tussenhandel	1	2	3	4	5	110
	f. Door consumentenorganisaties, zoals de ConsumentenBond	1	2	3	4	5	111
	g. Door milieu-actiegroepen	1	2	3	4	5	112
	h. Door uw leveranciers	1	2	3	4	5	113
	i. Door activiteiten van concurrenten	1	2	3	4	5	114

Blok 6 Vragen over wat het IC Ecodesign-project in uw bedrijf op gang heeft gebracht

In dit blok wordt gefocust op wat het IC Ecodesign-project heeft veranderd in uw bedrijfsvoering. De vragen gaan over uw kennistoename op MPO-gebied, over vervolgactiviteiten in uw bedrijf en over eventuele standaardisatie van MPO-richtlijnen in uw produktontwikkeling.

51.	Hieronder volgt een aantal vragen over in hoeverre het IC Ecodesign-project u meer inzicht gegeven heeft in het wat en hoe van MPO.	geheel niet	nauwelijks	enigszins	beperkte mate	sterke mate	
	a. In welke mate is uw kennis over MPO in het algemeen toegenomen?	1	2	3	4	5	115
	b. Is uw kennis toegenomen over de milieuaspecten van materialen die in uw produkten worden toegepast?	1	2	3	4	5	116
	c. Is uw inzicht toegenomen in de milieubelasting van uw produkt in zijn gehele levenscyclus?	1	2	3	4	5	117
	d. Is uw kennis toegenomen over wetgeving omtrent milieu-aspecten van produkten?	1	2	3	4	5	118
	e. In welke mate bent u nu voorbereid op de terugnameplicht?	1	2	3	4	5	119

	Vervolg van vraag 51:	geheel niet	nauwelijks	enigszins	beperkte mate	sterke mate
	f. Kan uw bedrijf nu zelfstandig MPO toepassen?	1	2	3	4	5
	g. In hoeverre is tijdens het project gericht gezocht naar informatie over MPO?	1	2	3	4	5
	h. In welke mate is rond MPO nieuwe samenwerking binnen uw bedrijfskolom ontstaan (leveranciers, afnemers en verwerkers)?	1	2	3	4	5
	i. In welke mate is rond MPO nieuwe samenwerking ontstaan met andere bedrijven binnen uw branche?	1	2	3	4	5
	j. In welke mate is rond MPO samenwerking ontstaan met nieuwe kennisleveranciers, zoals adviesburo's en universiteiten?	1	2	3	4	5
52.	**De MPO-Kredietregeling van het Ministerie van Economische Zaken is bedoeld om MPO binnen bedrijven te stimuleren. Bent u van plan van deze regeling gebruik te gaan maken?**	• ja • nee • deze regeling is mij onbekend				1 2 3

Vervolgactiviteiten zijn de MPO-activiteiten die u heeft ondernomen nadat u met uw IC-adviseur het adviesrapport 'EcoScan' heeft besproken. Hieronder volgt een aantal vragen over de vervolgactiviteiten in uw bedrijf.

53.	**Heeft u een haalbaarheidsstudie uitgevoerd of laten uitvoeren?**	• ja • nee		1 2
54.	**Zo ja, op welke wijze werd of wordt de haalbaarheidsstudie uitgevoerd?** *Indien gewenst kunt u 2 antwoordcijfers omcirkelen*	• via een intern onderzoek • via een (afstudeer)student • via een extern buro		1 2 3
55.	**Als de haalbaarheidsstudie is uitgevoerd door een extern buro, wilt u dan hiernaast de naam van het buro noteren?**	....		

		ja	nee	niet relevant
56.	Hieronder volgt een serie vragen over welke vervolgactiviteiten u inmiddels hebt ondernomen.			
	a. Heeft u inmiddels het MPO-advies toegepast op één of meer andere produkten?	1	2	3
	b. Bent u van plan om het MPO-advies te gaan toepassen op uw produkten?	1	2	3
	c. Heeft u de financiële gevolgen van één of meer geadviseerde verbeteropties berekend?	1	2	3
	d. Bent u na de scan nog op zoek geweest naar specifieke MPO-informatie?	1	2	3
	e. Heeft u na de scan MPO-software toegepast of laten toepassen?	1	2	3
	f. Heeft iemand namens uw bedrijf na de scan één of meer MPO-bijeenkomsten bezocht?	1	2	3
	g. Heeft u of één van uw medewerkers een MPO-cursus gevolgd?	1	2	3
	h. Bent u van plan om een MPO-cursus te (laten) volgen ?	1	2	3
	i. Heeft u een vervolgactiviteit opgezet, die hierboven niet is genoemd? Zo ja, wilt u deze hieronder kort beschrijven?	1	2	3

Hieronder volgt een aantal vragen over de wijze waarop het onderwerp MPO binnen uw bedrijf is besproken.

57.	**Wie binnen uw bedrijf heeft of hebben aan het IC-project deelgenomen?** *Indien gewenst kunt u 2 antwoordcijfers omcirkelen.*	• uzelf • een collega • meer collega's		1 2 3
58.	**Hoe groot was de waardering van deze collega('s) voor het IC Ecodesign-project?** *Geef dit a.u.b. aan met een rapportcijfer tussen de 1 en 10.*	waardering van collega('s):		.....

		wel	niet	niet relevant
59.	**Met welke van de volgende personen binnen uw bedrijf heeft u ooit het IC-project besproken?**			
	a. Met het bedrijfsmanagement	1	2	3
	b. Met uw produktontwikkelaar(s)	1	2	3
	c. Met uw marketing- of verkoopafdeling	1	2	3
	d. Met uw milieumanager	1	2	3
	e. Met uw kwaliteitsmanager	1	2	3
	f. Met uw inkoper(s)	1	2	3
	g. Met de afdeling produktie	1	2	3
	h. Met iemand anders	1	2	3

		nooit	zelden	soms	regelmatig	vaak	niet relevant
60.	Hieronder volgt een aantal vragen over de mate waarin u over MPO communiceert met partijen buiten uw bedrijf.						
	a. Specificeert uw bedrijf milieu-eisen bij de inkoop van onderdelen?	1	2	3	4	5	6
	b. Specificeert uw bedrijf milieu-eisen bij uitbesteding van produktie van onderdelen?	1	2	3	4	5	6
	c. Specificeert uw bedrijf milieu-eisen bij uitbesteding van produktontwikkeling aan externe produktontwikkelaars?	1	2	3	4	5	6

	Vervolg op vraag 60	nooit	zelden	soms	regel-matig	vaak	niet relevant	
	d. Hoe vaak gebruikt u uw MPO-inspanning als verkoopargument?	1	2	3	4	5	6	154
	e. Hoe vaak heeft u over milieu-aspecten gesproken met uw klanten?	1	2	3	4	5	6	155
	f. Hoe vaak worden milieu-aspecten opgenomen in uw offertes aan klanten?	1	2	3	4	5	6	156
	g. Hoe vaak heeft u over uw produkt contact opgenomen met her- of eindverwerkers?	1	2	3	4	5	6	157

61.	Hieronder volgt aan aantal vragen over documentatie op het gebied van MPO.	ja	nee	niet relevant	
	a. Heeft u één of meer toeleveranciers gevraagd een vrijwaringsverklaring te ondertekenen?	1	2	3	158
	b. Heeft u één of meer toeleveranciers gevraagd te garanderen om de geleverde produkten na afdanking terug te nemen en te (her)verwerken?	1	2	3	159
	c. Wordt de MPO-inspanning van uw bedrijf genoemd in uw jaarverslag?	1	2	3	160
	d. Noemt u uw MPO-inspanning in uw bedrijfsblad?	1	2	3	161
	e. Noemt u uw MPO-inspanning in overige bedrijfspublicaties?	1	2	3	162

Bedrijven kunnen milieurichtijnen standaard opnemen in hun bedrijfsvoering, o.a. door ze op te nemen in schriftelijke procedures en door duidelijke verantwoordelijkheden te stellen. In dit deel volgt een aantal vragen over deze onderwerpen.

62.	Onderstaand volgt een aantal vragen over MPO en schriftelijke procedures bij produktontwikkeling.	nooit	zelden	soms	regel-matig	bij elk project	niet relevant	
	a. Hoe vaak worden milieu-richtlijnen opgenomen in procedures voor produktplanning?	1	2	3	4	5	6	163
	b. Hoe vaak worden milieu-richtlijnen verwerkt in de produktspecificaties van uw produkten?	1	2	3	4	5	6	164
	c. Hoe vaak wordt voor MPO een apart budget vastgesteld bij de start van produktontwikkelingstrajecten?	1	2	3	4	5	6	165

63.	Een bedrijf kan besluiten een aantal MPO-richtlijnen op te stellen, dat gebruikt wordt tijdens produktontwikkelingsprocessen. *Hieronder volgt een serie vragen over dit onderwerp.*	ja	*nee*	*niet relevant*	
	a. Heeft uw bedrijf een eigen MPO-handleiding ontwikkeld of laten ontwikkelen?	1	2	3	166
	b. Heeft uw bedrijf een standaard checklist ontwikkeld die toegepast wordt bij produktontwikkeling?	1	2	3	167
	c. Worden milieurichtlijnen verwerkt in het kwaliteitszorgsysteem?	1	2	3	168
	d. Worden milieurichtlijnen verwerkt in het milieuzorgsysteem?	1	2	3	169

64.	**Aan welke personen binnen uw bedrijf is de verantwoordelijkheid voor de milieu-aspecten van uw produkten expliciet toegewezen?** *Indien gewenst kunt u 3 antwoordcijfers omcirkelen.*			
		• aan niemand in het bijzonder	1	
		• aan het bedrijfsmanagement	2	
		• aan de afdeling produktontwikkeling	3	170
		• aan de milieumanager	4	171
		• aan de kwaliteitszorgmanager	5	172
		• aan de afdeling inkoop	6	
		• aan de afdeling marketing of verkoop	7	
		• aan andere personen binnen het bedrijf	8	

Blok 7 Vragen over bedrijfseconomische aspecten van milieugerichte produktontwikkeling

MPO kan diverse bedrijfseconomische voordelen maar ook lasten zich meebrengen. Hieronder volgt een aantal vragen over dit onderwerp.

65.	**In welke mate worden de volgende kostenposten voor het *produkt door MPO beïnvloed?***	*neemt sterk toe*	*neemt toe*	*blijft gelijk*	*neemt af*	*neemt sterk af*	*niet relevant*	
	a. De kostenpost 'inkoop van materialen en onderdelen'	1	2	3	4	5	6	173
	b. De kostenpost 'afvalverwijderingskosten'	1	2	3	4	5	6	174
	c. De kostenpost 'produktiekosten'	1	2	3	4	5	6	175
	d. De kostenpost 'verpakkingskosten'	1	2	3	4	5	6	176
	e. De kostenpost 'transportkosten'	1	2	3	4	5	6	177
	f. De kostenpost 'toekomstige verplichte terugname'	1	2	3	4	5	6	178
	g. De kosten voor 'onderzoek en ontwikkeling'	1	2	3	4	5	6	179

	Vervolg op vraag 65	neemt sterk toe	neemt toe	blijft gelijk	neemt af	neemt sterk af	niet relevant	
	h. Een andere kostenpost, Namelijk:	1	2	3	4	5	6	180
	....							181
66.	**In welke mate verwacht u dat de verkoopcijfers van het produkt zullen stijgen door de volgende factoren?**	geheel niet	nauwe-lijks	enigs-zins	beperkte mate	sterke mate	niet relevant	
	a. Het vergroten van het marktaandeel op bestaande markten	1	2	3	4	5	6	182
	b. Het betreden van nieuwe markten	1	2	3	4	5	6	183
67.	**Hoe groot schat u dat het totale bedrijfseconomische voordeel van MPO over twee jaar zal zijn?** *Noteer dit a.u.b. als een percentage.*			bedrijfseconomisch voordeel:			..... %	184

	Blok 8 Vragen over uw waardering voor het IC Ecodesign-project						
	Tot slot willen we u persoonlijk een aantal vragen stellen over uw waardering voor het IC Ecodesign-project.						
68.	**Wat is uw functie in het bedrijf?**	• (mede)direkteur • hoofd produktontwikkeling • milieuverantwoordelijke • anders, namelijk:				1 2 3 4	185 186
69.	**Hoe kenschetst u uw eigen houding ten aanzien van het onderwerp milieugerichte produktontwikkeling?**	afwij-zend	kritisch	afwach-tend	actief	zeer actief	
		1	2	3	4	5	187
70.	**Hoe groot is uw persoonlijke waardering voor het IC Ecodesign-project?** *Geef dit a.u.b. aan met een rapportcijfer tussen de 1 en 10.*			persoonlijke waardering:		.....	188
71.	Onderstaand volgt een aantal vragen over het IC Ecodesign-project.	geheel niet	nauwe-lijks	enigs-zins	beperkte mate	sterke mate	
	a. Leidt het IC-project bij uw bedrijf tot concrete resultaten?	1	2	3	4	5	18
	b. Zou u deelname aan het project bij andere bedrijven aanbevelen?	1	2	3	4	5	19
	c. Zult u één of meer elementen van de Milieu Innovatie Scan blijven gebruiken? **Zo ja, kunt u deze elementen hieronder noemen?**	1	2	3	4	5	19 19
72.	Het MPO-strategieënwiel was één van de denkmodellen die tijdens de scan zijn gebruikt. De volgende vragen gaan over dit model.	geheel niet	nauwe-lijks	enigs-zins	beperkte mate	sterke mate	
	a. Weet u zich het MPO-strategieënwiel nog voor de geest te halen?	1	2	3	4	5	19
	b. Vindt u het model inzichtelijk qua opbouw?	1	2	3	4	5	19
	c. Vindt u het zinvol om een dergelijk model toe te passen in uw bedrijf?	1	2	3	4	5	19
	d. Verwacht u dit model te blijven gebruiken?	1	2	3	4	5	19

Dit is het einde van de vragenlijst. Hartelijk dank voor uw medewerking!

Heeft u wellicht nog suggesties ter verbetering van de methodiek van het IC Ecodesign-project? Dan zouden wij het zeer op prijs stellen als u deze hieronder wilt noteren.

....

....

....

....

....

Appendix C Stimuli and barriers

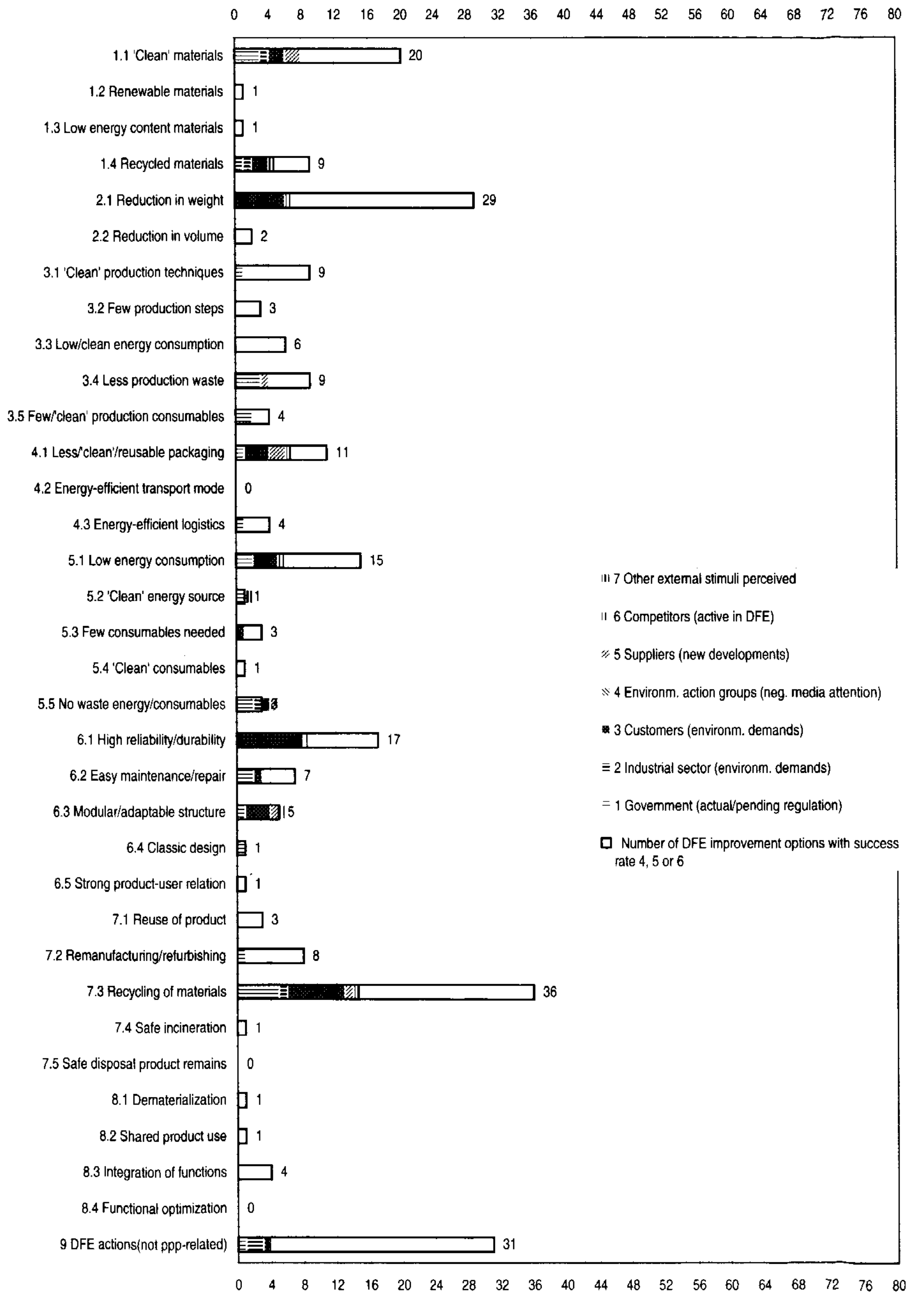

Figure C.1 *External stimuli (87 in all) for the 247 DFE improvement options with success rate 4, 5 or 6*

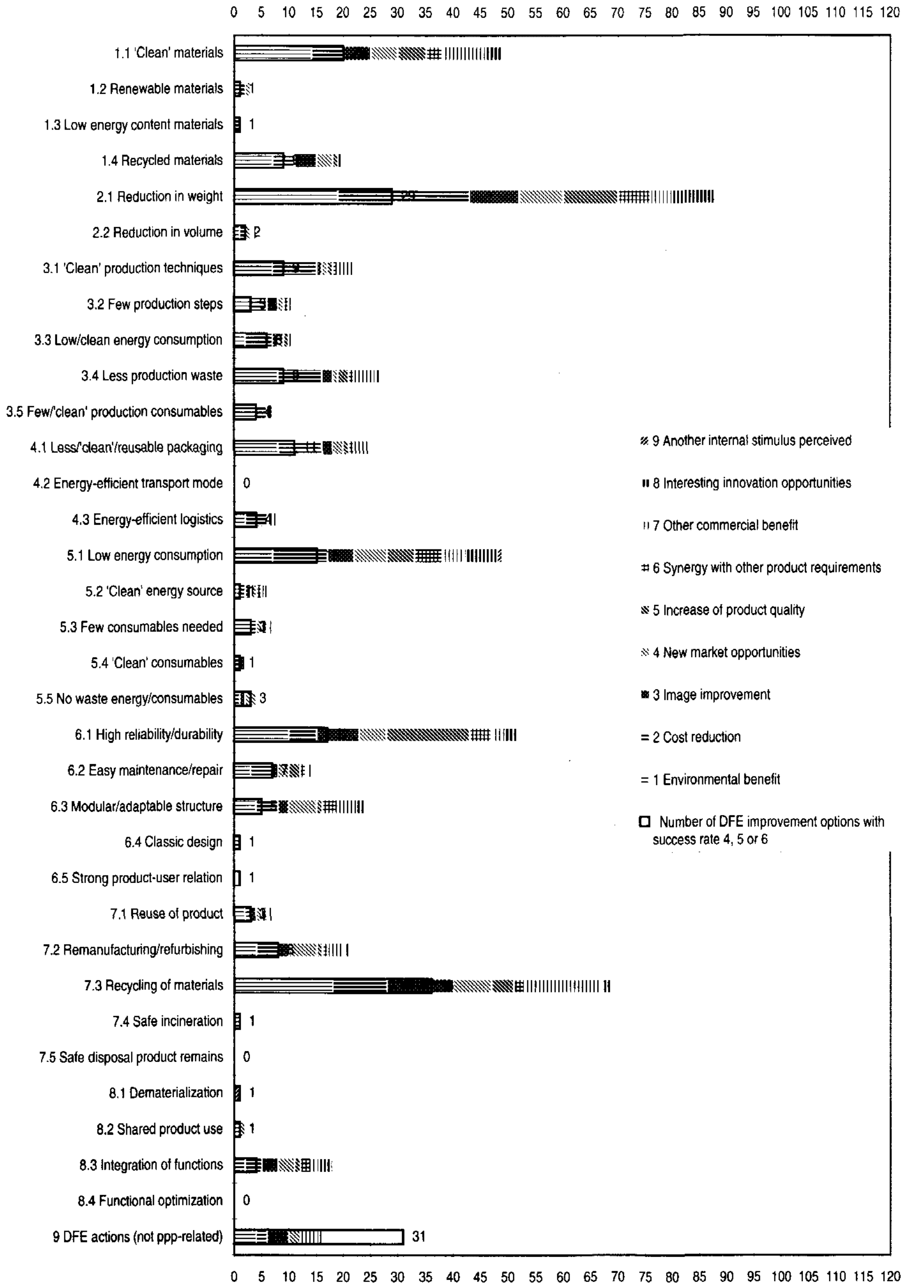

Figure C.2 *Internal stimuli (570 in all) for the 247 DFE improvement options with success rate 4, 5 or 6*

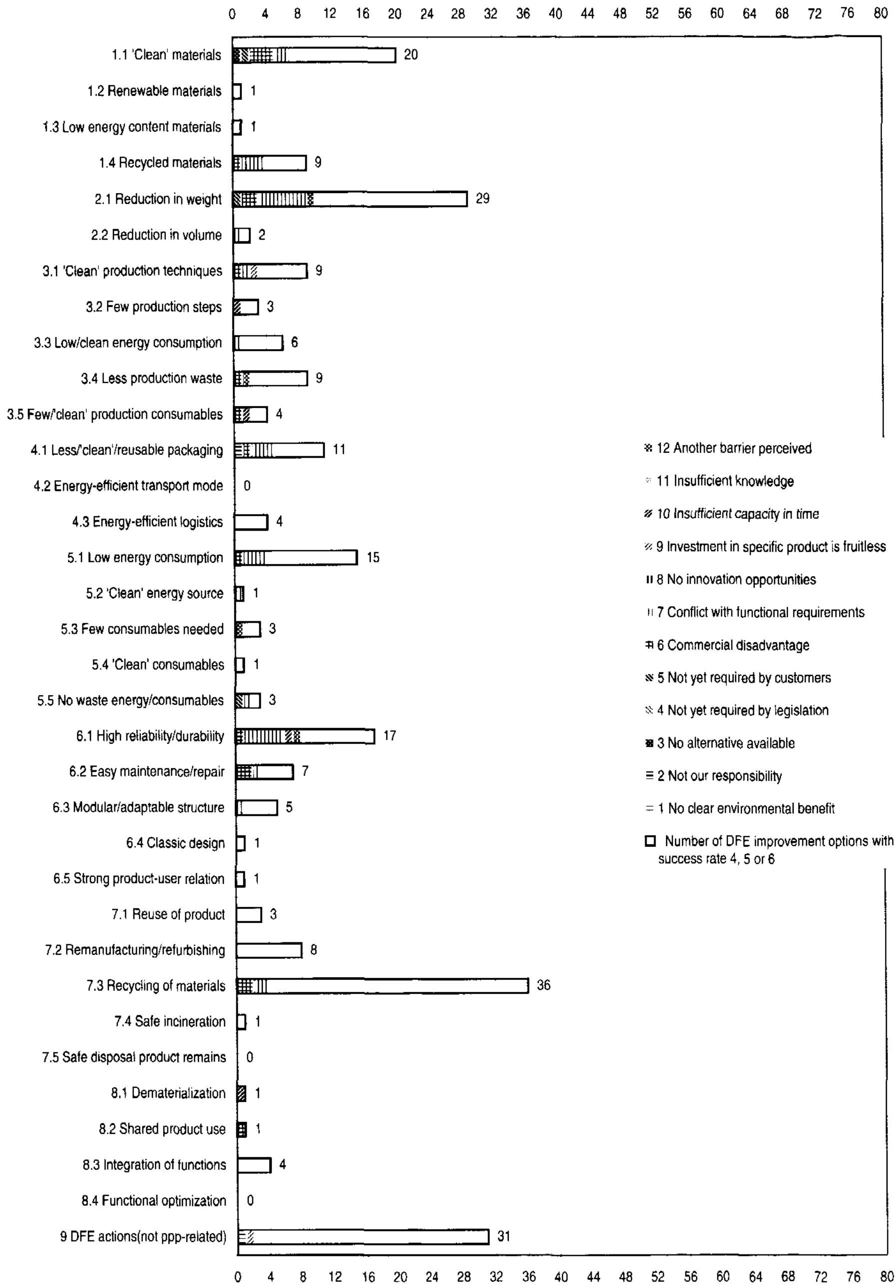

Figure C.3 *Barriers (65 in all) for the 247 DFE improvement options with success rate 4, 5 or 6*

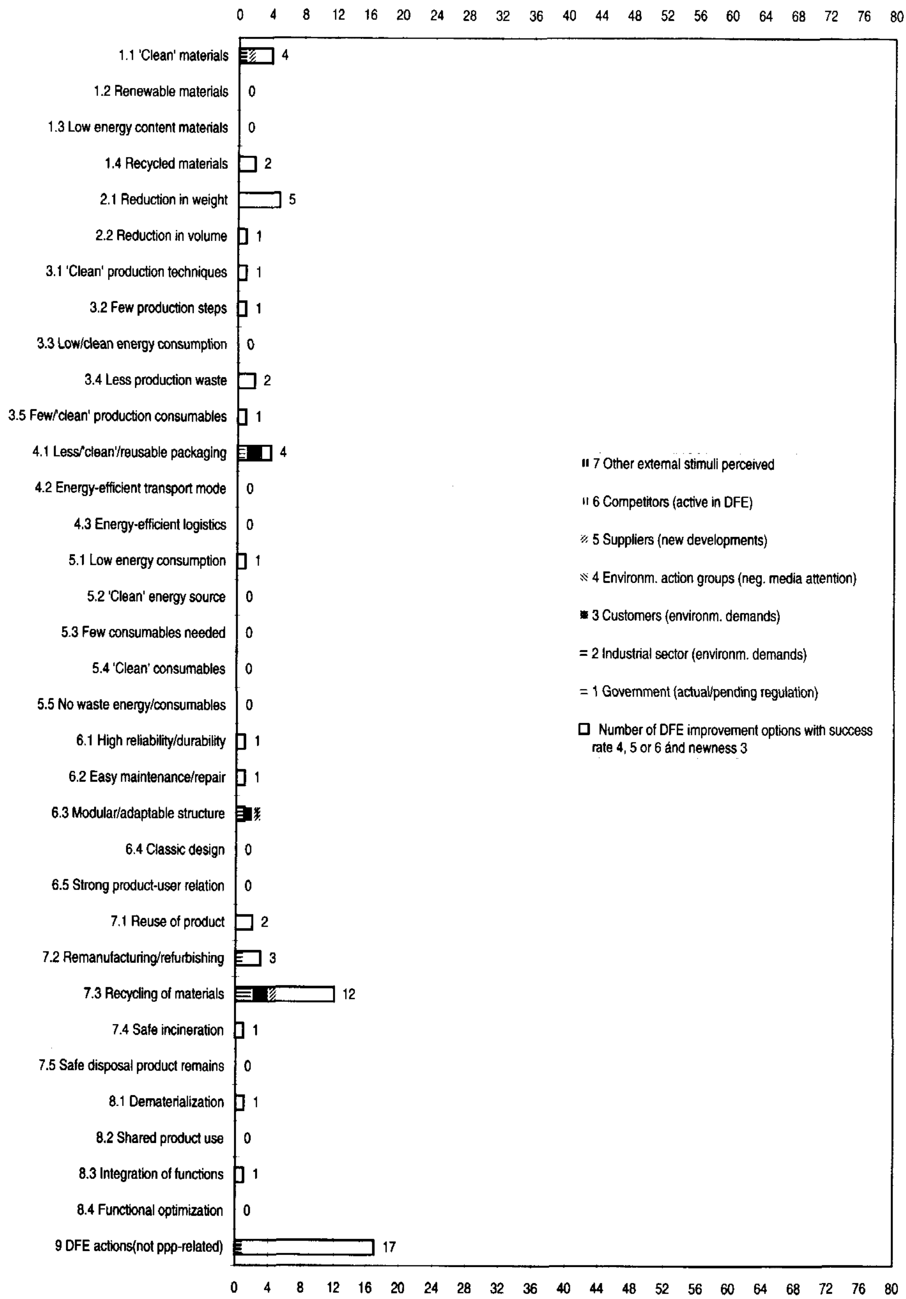

Figure C.4 *External stimuli (12 in all) for the 51 DFE improvement options with success rate 4, 5 or 6 ánd newness 3*

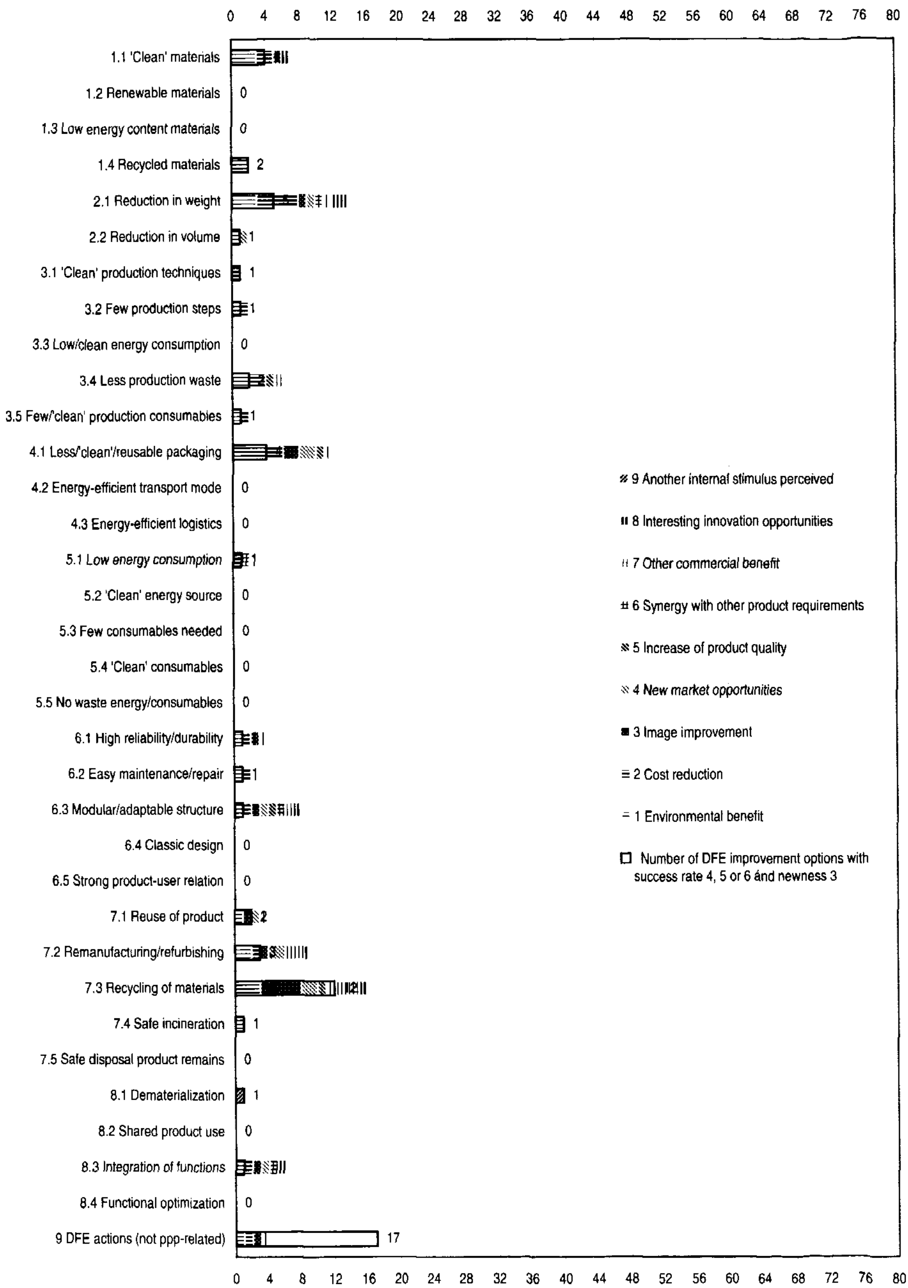

Figure C.5 *Internal stimuli (107 in all) for the 51 DFE improvement options with success rate 4, 5 or 6 ánd newness 3*

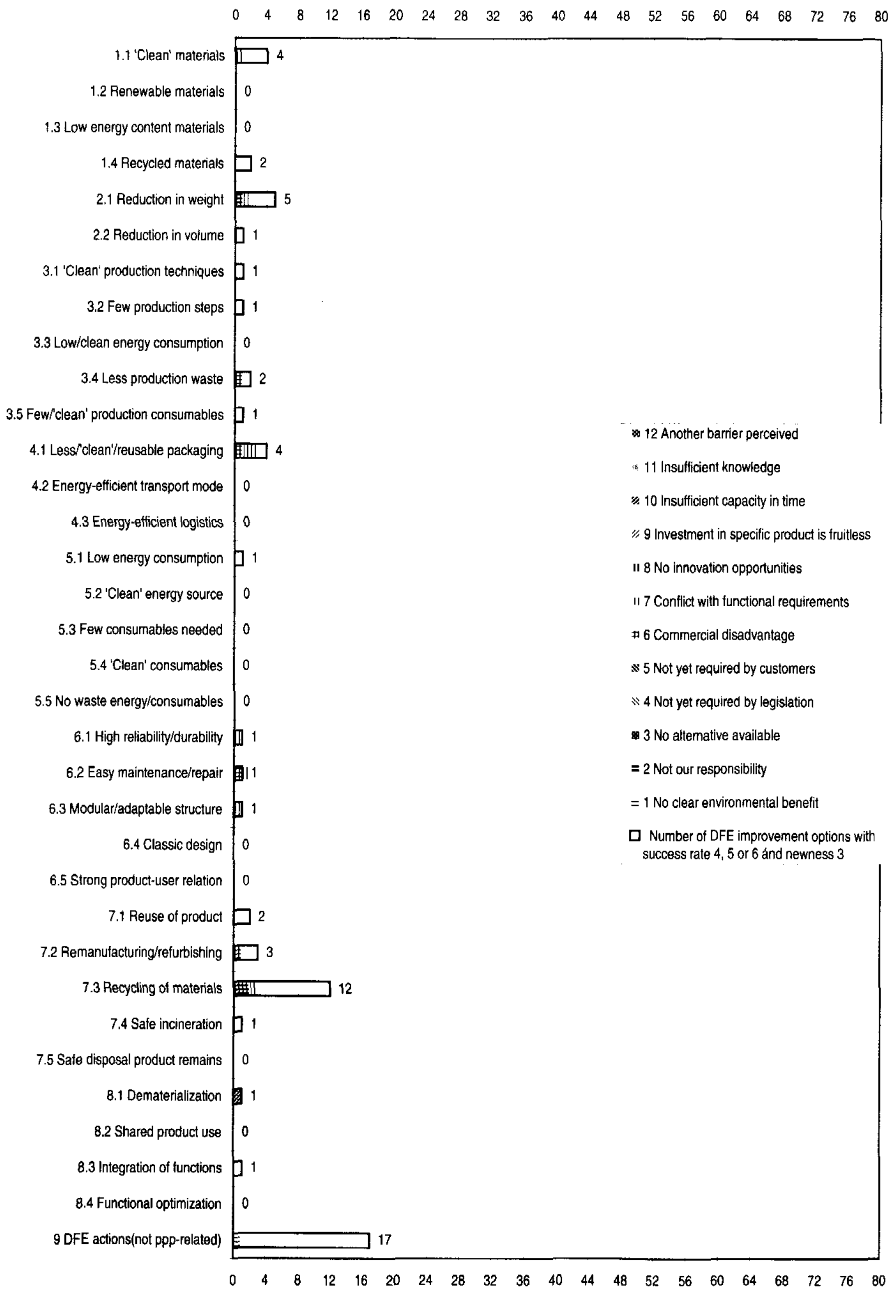

Figure C.6 *Barriers (17 in all) for the 51 DFE improvement options with success rate 4, 5 or 6 ánd newness 3*

Appendix D Characteristics

The figures in the right column are the mean scores the respondents gave on a scale ranging from 1 (negative/ do not agree) to 5 (positive / do agree).
The percentages per variable do not add up to 100% since the missing cases are included in the calculation of percentages, although they are not listed in the tables below.

Table D.1 Algemene bedrijfskarakteristieken

1	Gebruikt u schriftelijke procedures zoals checklists bij uw produktontwikkeling? (n=71)	v022	• ja	42.3%	
			• nee	34.6%	
			• niet relevant	16.7%	
2	Stelt u altijd zelf de produktspecificaties op voor de produkten die u verkoopt? (n=74)	v023	• ja	56.4%	
			• nee	25.6%	
			• niet relevant	10.3%	
3	Levert u een produkt dat direkt geleverd kan worden aan de eindgebruiker (een 'eindprodukt')? (n=72)	v024	• ja	75.6%	
			• nee	14.1%	
4	Wat is de kernactiviteit van uw bedrijf? (n=75)	v026	• ontwikkeling, produktie, assemblage en verkoop	60.3%	
			• ontwikkeling, assemblage en verkoop	9.0%	
			• ontwikkeling en verkoop	10.3%	
			• voornamelijk verkoop	5.1%	
			• anders	9.0%	
5	Hoe innovatief is uw bedrijf vergeleken met uw belangrijkste concurrenten? (n=72)	v042	veel minder	1.3%	3.7
			minder	3.8%	
			gelijk	28.2%	
			meer	43.6%	
			veel meer	10.3%	
6	Beschikt uw bedrijf over een kwaliteitszorgsysteem? (n=74)	v050	• ja, ISO-gecertificeerd	26.9%	
			• ja, maar niet ISO-gecertificeerd	30.8%	
			• nee	34.6%	

Table D.2 De factor milieu in de bedrijfsvoering

1	Beschikt uw bedrijf over een milieuzorgsysteem? (n=75)	v051	• ja	11.5%	
			• ten dele (partieel systeem)	29.5%	
			• nee	52.6%	
2	Nam uw bedrijf deel aan het IC-project Schoner Produceren? (n=75)	v052	• ja	5.1%	
			• nee	62.8%	
			• onbekend	25.6%	
3	Heeft uw bedrijf een milieu-convenant ondertekend? (n=74)	v053	• ja	6.4%	
			• nee	65.4%	
			• onbekend	20.5%	
4	Hoe groot schat u de milieu-inspanningen van uw bedrijf sinds 1 januari 1991, vergeleken met de milieu-inspanning van uw concurrenten? (n=70)	v054	veel kleiner	0%	3.3
			kleiner	2.6%	
			gelijk	53.8%	
			groter	28.2%	
			veel groter	1.3%	
5	Bij wie binnen uw bedrijf liggen de uitvoerende milieutaken (o.a. beheer van milieu-vergunningen) op dit moment? (n=74)	v056	• bij niemand in het bijzonder	19.2%	
			• bij de milieumanager	1.3%	
			• bij de kwaliteitszorgmanager	5.1%	
			• bij de afdeling produktie	7.7%	
			• bij het bedrijfsmanagement	47.4%	
			• bij een andere medewerker	10.3%	

Table D.3 Vragen over milieugerichte produktontwikkeling bij uw bedrijf

	Onderstaand volgt een aantal stellingen over MPO. Wilt u aangeven in hoeverre u het met deze stellingen al dan niet eens bent?	zeer mee oneens	oneens	neutraal	eens	zeer mee eens
1	a. MPO is voor ons bedrijf een kans om financieel voordeel te behalen. (n=75) v057	6.4%	10.3%	33.3%	37.2%	6.4%
2	b. Ons bedrijf kan MPO gebruiken als verkoopargument in de marketing (n=75) v058	2.6%	9.0%	24.4%	51.3%	6.4%
3	c. Wetgeving maakt MPO voor ons bedrijf noodzakelijk (n=75) v059	2.6%	21.8%	37.2%	26.9%	5.1%
4	d. Voor ons bedrijf levert MPO kosten noch baten op (n=74) v060	3.8%	29.5%	48.7%	9.0%	0%
5	e. Voor ons bedrijf is MPO een kostenpost die zich op de lange termijn terugverdient. (n=74) v061	2.6%	14.1%	38.5%	34.6%	2.6%
6	f. Voor ons bedrijf is MPO een kostenpost die zich op de lange termijn niet terugverdient. (n=74) v062	10.3%	35.9%	42.3%	3.8%	0%
	Wat is de houding ten opzichte van milieugerichte produktontwikkeling van de volgende personen in uw bedrijf?	zeer afwijzend	afwijzend	neutraal	betrokken	zeer betrokken
7.	a. het bedrijfsmanagement (n=74) v065	0%	1.3%	24.4%	59.0%	6.4%
8.	b. de afdeling produktontwikkeling (n=73) v066	0%	0%	20.5%	46.2%	15.4%
9.	c. de afdeling marketing en/of verkoop (n=73) v067	0%	0%	35.9%	44.9%	3.8%
10.	d. de afdeling milieuzaken (n=72) v068	0%	0%	24.4%	23.1%	6.4%
11.	e. de afdeling kwaliteitszorg (n=73) v069	0%	0%	30.8%	38.5%	2.6%
12.	f. de afdeling inkoop (n=74) v070	0%	1.3%	33.3%	44.9%	1.3%
13.	g. de afdeling produktie (n=71) v071	0%	2.6%	43.6%	37.2%	2.6%
14.	Wie heeft MPO als eerste bij uw bedrijf op de agenda gezet? (n=74) v072	• uw IC-adviseur • uzelf • één van uw medewerkers • één van uw afnemers • iemand anders • IC-adviseur + uzelf				28.2% 34.6% 10.3% 2.6% 10.7% 5.1%

Table D.4 Motivatie voor deelname aan het IC EcoDesign-project

	In welke mate hebben de volgende argumenten meegespeeld bij uw beslissing om aan het IC Ecodesign-project deel te nemen?	geheel niet	nauwelijks	enigszins	beperkte mate	sterke mate
1	a. U was op zoek naar een milieuvriendelijk alternatief voor een materiaal of onderdeel (n=73) v073	15.4%	16.7%	10.3%	24.4%	23.1%
2	b. U nam deel omdat u zich persoonlijk betrokken voelt bij 'het milieu' (n=73 v074	3.8%	9.0%	29.5%	30.8%	17.9%
3	c. Uw bedrijf had zich expliciet ten doel gesteld het milieu-profiel van de produkten te verbeteren (n=72) v075	12.8%	26.9%	23.1%	15.4%	11.5%
4	d. U wilde weten hoe groot de milieubelasting van uw produkt ten opzichte van concurrerende produkten is (n=72) v076	16.7%	23.1%	17.9%	16.7%	14.1%
5	e. U wilde ingelicht worden over wetgeving op het gebied van MPO (n=73) v077	15.4%	12.8%	28.2%	26.9%	7.7%
6	f. U ziet MPO als een belangrijk aspect van produktinnovatie (n=74) v078	1.3%	7.7%	19.2%	39.7%	23.1%
7	g. U ziet een lage milieubelasting als onderdeel van produktkwaliteit (n=72) v079	6.4%	15.4%	35.9%	30.8%	1.3%
8	h. U ziet MPO als middel om de efficiency in uw bedrijfsvoering te verhogen (n=74) v080	5.1%	25.6%	21.8%	30.8%	7.7%
9	i. U wilt op alle gebieden bijblijven, dus ook op het gebied van MPO (n=74) v081	0%	6.4%	17.9%	42.3%	25.6%
10	j. Afnemers stellen steeds hogere milieu-eisen aan onze produkten (n=73) v082	7.7%	24.4%	7.7%	38.5%	12.8%
11	k. U wilde weten of uw produkt het risico liep een negatief milieu-imago te krijgen (n=73) v083	16.7%	25.6%	29.5%	10.3%	7.7%
12	l. U wilde uw achterstand op het gebied van MPO ten opzichte van uw concurrent inlopen (n=73) v084	29.5%	37.2%	12.8%	6.4%	1.3%
13	m. U wilde een 'second opinion' om hiermee uw 'groene marketing-claim' te kunnen onderbouwen (n=73) v085	24.4%	28.2%	15.4%	11.5%	10.3%
14	n. Aan het project waren subsidiemogelijkheden verbonden (n=74) v086	25.6%	20.5%	16.7%	17.9%	11.5%
15	o. U wilde uw IC-adviseur een plezier doen door deel te nemen (n=72) v087	44.9%	21.8%	10.3%	5.1%	7.7%

Table D.5	**Karakteristieken van het geselecteerde produkt**		
1	Wat is het afzetgebied van het produkt? (n=74) v002	• met name Nederland • met name Nederland en Duitsland • West Europa • geheel Europa • met name de V.S. • wereldwijd • anders	34.6% 6.4% 21.8% 14.1% 0 15.4% 6.4%
2	Wat waren, op het moment van de scan, uw ontwikkelingsplannen ten aanzien van het geselecteerde produkt? (n=74) *Indien gewenst kunt u 2 antwoordcijfers omcirkelen.* v008	• dit produkt was juist toe aan een flinke herontwerpslag • een herontwerptraject voor dit produkt was in volle gang • een herontworperptraject hiervoor was juist afgesloten • dit produkt was zojuist nieuw ontwikkeld • dit produkt was niet toe aan enige produktontwikkeling • u keek uit naar een geheel nieuw produktconcept; wijziging van het geselecteerde produkt was ongewenst • optimalisatie traject was gaande • anders	20.3% 17.7% 1.2% 16.5% 8.8% 16.5% 8.1% 9.9%
3	In welke fase van de produktlevenscyclus bevond het geselecteerde produkt zich tijdens de scan? (n=70) v011	• introductie: het produkt was juist op de markt gebracht • groei: het marktaandeel was groeiende • volwassenheid: het marktaandeel stagneerde • verval: het marktaandeel was aan het zakken	25.6% 29.5% 28.2% 3.8%
4	Op welk type markt wordt het produkt voornamelijk afgezet? (n=73) v013	• consumentenmarkt • industriële markt • overheid en publieke sektor • consumenten- en industriële markt • industriële markt en overheid	38.5% 35.9% 9.0% 3.8% 3.8%
5	Waarom is juist dit produkt geselecteerd voor de scan? (n=75) v014sel1-7	• dit produkt is ons enige produkt • de milieuproblematiek rond dit produkt leek redelijk overzichtelijk • rond dit produkt was milieu-wetgeving in ontwikkeling • dit produkt was aan een herontwerpslag toe • we verwachten marktkansen door juist dit produkt milieukundig te verbeteren • anders	16.2% 15.2% 11.4% 20.0% 25.7% 11.4%

Table D.6 Stimuli voor milieugerichte produktontwikkeling vanuit de omgeving

1	Via een vrijwaringsverklaring garandeert een leverancier dat zijn produkt bepaalde stoffen niet bevat. Heeft uw bedrijf voor één of meer afnemers een zogenaamde 'vrijwaringsverklaring' ondertekend? (n=75)	v094	• ja • nee • onbekend				17.9% 60.3% 15.4%
2	Heeft uw bedrijf aan één of meer afnemers de garantie gegeven uw produkten na gebruik terug te nemen en te (her)verwerken? (n=73)	v095	• ja • nee • onbekend				9.0% 76.9% 6.4%
3	Heeft uw branche een milieu-convenant met de overheid afgesloten? (n=75)	v096	• ja • nee • onbekend				11.5% 57.7% 24.4%
4	Is uw bedrijf ooit doelwit geweest van een actie van een milieu-organisatie? (n=75)	v097	• ja • nee • onbekend				0% 93.6% 0%
5	Is uw branche ooit doelwit geweest van een actie van een milieu-organisatie? (n=74)	v098	• ja • nee • onbekend				7.7% 60.3% 25.6%
	Hoe beoordeelt u de houding inzake MPO van de volgende partijen?		zeer afwijzend	afwijzend	neutraal	betrokken	zeer betrokken
6	a. Van bovengenoemde branche-organisatie(s) (n=72)	v099	0%	2.6%	50%	29.5%	3.8%
7	b. Van de Nederlandse overheid (n=74)	v100	1.3%	1.3%	32.1%	46.2%	10.3%
8	c. Van uw direkte afnemers (n=74)	v101	0%	3.8%	65.4%	17.9%	3.8%
9	d. Van de eindgebruikers van uw produkt (n=74)	v102	0%	0%	70.5%	16.7%	2.6%
10	e. Van de tussenhandel, zoals uw dealers (n=74)	v103	0%	2.6%	64.1%	15.4%	1.3%
11	f. Van uw leveranciers (n=74)	v104	0%	5.1%	55.1%	25.6%	2.6%
12	g. Van uw concurrenten (n=73)	v105	0%	6.4%	66.7%	14.1%	1.3%
	In welke mate wordt u door de volgende factoren gestimuleerd om MPO toe te passen bij uw produktontwikkeling?		geheel niet	nauwelijks	enigszins	beperkte mate	sterke mate
13	a. Door uw branche (n=70)	v106	20.5%	29.5%	21.8%	10.3%	2.6%
14	b. Door overheidsregelingen (n=73)	v107	11.5%	20.5%	21.8%	21.8%	14.1%
15	c. Door uw direkte afnemers (n=72)	v108	15.4%	24.4%	21.8%	14.1%	12.8%
16	d. Door eindgebruikers (n=72)	v109	17.9%	28.2%	20.5%	17.9%	3.8%
17	*e. Door de tussenhandel (n=72)*	v110	25.6%	26.9%	23.1%	9.0%	1.3%
18	f. Door consumentenorganisaties, bv. de ConsumentenBond (n=72)	v111	29.5%	28.2%	16.7%	15.4%	0%
19	g. Door milieu-actiegroepen (n=72)	v112	33.3%	24.4%	15.4%	10.3%	3.8%
20	h. Door uw leveranciers (n=72)	v113	26.9%	28.2%	24.4%	6.4%	1.3%
21	i. Door activiteiten van concurrenten (n=72)	v114	21.8%	28.2%	25.6%	7.7%	3.8%

Table D.7 Bedrijfseconomische aspecten van milieugerichte produktontwikkeling

	In welke mate worden de volgende kostenposten voor het produkt door MPO beïnvloed?		neemt sterk toe	neemt toe	blijft gelijk	neemt af	neemt sterk af	niet relevant
1	a. De kostenpost 'inkoop van materialen en onderdelen' (n=73)	v173	2.6%	29.5%	30.8%	15.4%	12.8%	6.4%
2	b. De kostenpost 'afvalverwijderingskosten' (n=73)	v174	2.6%	23.1%	17.9%	23.1%	1.3%	23.1%
3	c. De kostenpost 'produktiekosten' (n=73)	v175	1.3%	21.8%	34.6%	17.9%	3.8%	11.5%
4	d. De kostenpost 'verpakkingskosten' (n=73)	v176	3.8%	15.4%	32.1%	15.4%	2.6%	21.8%
5	e. De kostenpost 'transportkosten' (n=73)	v177	0%	9.0%	48.7%	15.4%	2.6%	15.4%
6	f. De kostenpost 'toekomstige verplichte terugname' (n=72)	v178	6.4%	25.6%	3.8%	7.7%	3.8%	42.3%
7	*g. De kosten voor 'onderzoek en ontwikkeling' (n=73)*	v179	9.0%	42.3%	19.2%	1.3%	0%	19.2%
	In welke mate verwacht u dat de verkoopcijfers van het produkt zullen stijgen door de volgende factoren?		geheel niet	nauwelijks	enigszins	beperkte mate	sterke mate	niet relevant
8	a. Het vergroten van het marktaandeel op bestaande markten (n=73)	v182	7.7%	12.8%	19.2%	24.4%	19.2%	7.7%
9	b. Het betreden van nieuwe markten (n=73)	v183	10.3%	16.7%	12.8%	11.5%	28.2%	11.5%
10	Hoe groot schat u dat het totale bedrijfseconomische voordeel van MPO over twee jaar zal zijn? *Noteer dit a.u.b. als een percentage.* (n=51)	v184					gemiddeld bedrijfseconomisch voordeel:	9.45%

Table D.8	**Waardering voor het IC Ecodesign-project**						
1	Wat is uw functie in het bedrijf? (n=74) v185	• (mede)direkteur • hoofd produktontwikkeling • milieuverantwoordelijke • anders				51.3% 16.7% 0% 24.4%	
2	Hoe kenschetst u uw eigen houding ten aanzien van het onderwerp milieugerichte productontwikkeling? (n=75)	afwij-zend	kritisch	afwach-tend	actief	zeer actief	
	v187	0%	16.4%	33.3%	44.9%	7.7%	3.6
3	Hoe groot is uw persoonlijke waardering voor het IC Ecodesign-project? *Geef dit a.u.b. aan met een rapportcijfer tussen de 1 en 10.* (n=75) v188	gemiddeld cijfer voor persoonlijke waardering:				7.0	
	Onderstaand volgt een aantal vragen over het IC Ecodesign-project.	geheel niet	nauwe-lijks	enigs-zins	beperkte mate	sterke mate	
4	a. Leidt het IC-project bij uw bedrijf tot concrete resultaten? (n=74) v189	10.3%	23.1%	23.1%	21.8%	14.1%	3.1
5	b. Zou u deelname aan het project bij andere bedrijven aanbevelen? (n=72) v190	2.6%	6.4%	15.4%	29.5%	35.9%	4.0
6	c. Zult u één of meer elementen van de Milieu Innovatie Scan blijven gebruiken? (n=68) v191	11.5%	12.8%	21.8%	24.4%	14.1%	3.2

Curriculum Vitae

Carolien van Hemel (1967) completed her studies at Delft University of Technology in 1992, graduating cum laude with an MSc in industrial design engineering. She subsequently practiced as an industrial designer for a year. Her motivation to specialize in design for the environment prompted her to engage upon a PhD research project at the Section for Environmental Product Development, Faculty of Industrial Design Engineering at the Delft University of Technology in 1993. In June 1998 she defended her PhD thesis entitled *EcoDesign empirically explored; Design for Environment in Dutch small and medium sized enterprises.*

Between 1993 and 1997 she published various articles and lectured on the topic of ecodesign implementation in industry. Together with J.C. Brezet, she published the UNEP manual on ecodesign entitled *EcoDesign; a promising approach to sustainable production and consumption* in 1997. Since 1994 she has been a member of the editorial board of *O2 Magazine*, the Dutch magazine on design for environment intended for industrial designers.

In 1997 she took up work in the private sector for the Atag Kitchen Group as a research project leader. One of her tasks here is to implement ecodesign in the seven companies that belong to this Dutch manufacturer of major kitchen appliances.