University of Bradford eThesis

A Plan-Do-Check-Act Framework for WEEE and RoHS

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MPhil

University of Bradford

— 2011 —

A Plan-Do-Check-Act Framework for WEEE and RoHS

A model for Implementing WEEE and RoHS by Integrating Eco-design Factors and Activities into Business Operation and Strategy

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MPhil

Submitted for the degree of

Master of Philosophy

School of Engineering, Design and Technology

University of Bradford

— 2011—

ABSTRACT

"A PLAN-DO-CHECK-ACT FRAMEWORK FOR WEEE and RoHS"

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Keywords

Eco-design, WEEE, RoHS, Design-For-Environment (DFE), Sustainable Development, Environmentally Conscious Manufacturing (ECM), Environmentally Conscious Design (ECD), Life Cycle Analysis (LCA), Environmentally Conscious Production (ECP), Life Cycle Thinking, ISO 14000, ISO 14001, Environmental Management System (EMS), Eco-design Framework, Plan-Do-Check-Act (PDCA) Improvement Cycle, Recycling, Reuse.

Eco-design is relatively new and fast growing field of research due to its vital importance to the manufacturing industry and its related environmental issues such as reducing waste, and CO2 emission. A major EU programme relating to the environment is the waste of Electrical and Electronic Equipment (WEEE) directive. The (WEEE) directive specifies ten categories and a voltage range which is up to 1.000 volts AC or 1.500volts DC.

The developed framework came for the implementation of Eco-design principles that helps to take into account the adaption of the (WEEE) directive and the restriction of hazard substances (RoHS) used in electrical and electronic equipments. As a result of identify gaps and needs such as a lack of a comprehensive Eco-design framework and the need to integrate it to the normal business operation.

In this research the PDCA framework for Eco-design and WEEE directive will be discussed. The framework will encompass all of the Eco-design's implementation and integration factors and activities such as WEEE and RoHS directives, Eco-design management, Environmental legislations, Eco-design tools and considerations. The literature review covers the topic of Eco-design's related issues, and WEEE and RoHS directives rules.

Based on comprehensive questionnaire survey of Eco-design, WEEE and RoHS issues and activities among a sample of environmentally aware companies, statistical analysis is carried out using SPSS software. Then the findings of the survey triangulated with the findings of the literature review formed the basis of the design and implementation plan of the proposed framework

ACKNOWLEDGEMENTS

This thesis would not have been possible without the support and cooperation of many other people. I would like to thank my supervisors Prof. Raed Abd-Alhameed and Dr. Chedly Tizaoui for their support and invaluable guidance throughout this research.

I owe my deepest gratitude to my husband for his unlimited support, motivation and encouragement throughout the course of this work. Huge thanks for my children for their patience and putting up with me while I was busy with the research.

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CHAPTER 1 INTRODUCTION

1.1 Background

During the last century, environmental problems were often seen as local problems due to the impact from a certain product. However, today it becomes more obvious that the problems are much more complex and related to all the phases in a product' lifecycle from extraction of material to waste or deposition of used product. Rapid technical developments during the last centuries have for example caused serious environmental impact, which can be regarded as an un-sustainable life style. The lack of sustainability is mainly caused by the current global situation. There are today at least four basic problems, which are more or less unsolved problems (Ljunberg, 2007):

- Over-consumption: The use of material and energy today for packing and product themselves has increased in many highly industrialised country from the end of the 19th century until today. China is the second largest energy consumer in the world, but studies indicate that the usage of renewable energy in China shows a promising prospect in the near future.

- Resources utilisation: The human productivity has not been able to co-operate with the nature regarding sustainability. Again resources scarcity have remained major constrains on China's development for several decades.

- Pollution: The earth is already seriously affected by the emissions so far, most polluted cities in the world are in China, India then Russia.

- Over-population: The world could have more than ten billions inhabitants by 2025. It is clear as to how this situation will lead to less sustainability with more and more environmental impact. Bangladesh boasts the highest population density in the world after that it come India and China.

Designing products, which poses less impact on the environment in terms of energy and materials throughout their whole life cycle would soon become a compulsory activity rather than a voluntary one. The question, which is facing businesses in this day and age, is ‘how can we develop and produce more sustainable products?’ (Ljunberg, 2007).

1.2 Appreciation of the challenges of the thesis

First carrying out a research in Eco-design is a challenge in itself due to number of reasons; the most prominent one is that Eco-design is still a relatively new subject.

The challenges faced by the author in his quest for information about Eco-design and then identifying gaps and future research opportunities are summarized as follows:

- Eco-design is a wide and general subject affecting all types of business, which involved in designing and producing products.

- Eco-design is like a person with many different names and passports, different authors would have different names for Eco-design, so research in Eco-design would involve using many key words such as design for environment, green design, environmentally friendly design, environmentally conscious design, environmentally conscious manufacturing, design for recycling, design for disassembly, so on and so forth. So, at the beginning of the research understanding what Eco-design was a challenge in itself.

- Information about Eco-design in the literature is structuring and understanding took a considerable time.

- Electrical and Electronic Equipment (EEE) is considered to produce one of the fastest-growing waste streams in Europe.

- In order to prevent negative environmental and social impacts, the WEEE needs to be handled, transported, stored and treated properly.

- The content of hazardous components in waste rising from Electrical and Electronic Equipment (WEEE) is a major concern that urges governments to take measures to ensure proper treatment and disposal.

- The European Union established re-use and recycling goals that the Member States are committed to reach. In particular, two Fundamental directives were issued: Directive 2002/96/EC of 27 January 2003 on Waste of Electrical and Electronic Equipment (WEEE), and Directive 2002/95/EC of 27 January 2003 on the Restriction of certain hazardous Substances (RoHS). These directives include some innovative and interesting issues.

The main contributions in this research:

- Developing a questionnaire about Eco-design, WEEE and RoHS issues and activities was a significant challenge in itself. So, the author has had to study and seek guidance from questionnaire developments in other disciplines such as health and safety, and total quality management.

- Design a framework, which helps in designing and producing environmentally friendly products.

1.3 Aims and objectives of the research

The main aim of this research is to develop a framework for the implementation of Eco-design principles that help to take into account the adaption of the waste of electrical and electronic equipment directive (WEEE), and the restriction of hazard materials (RoHS) use in Electrical and Electronic Equipments, and came as a result of identify gaps and needs such as a lack of a comprehensive Eco-design framework and the need to integrate it to the normal business operation.

The objectives of the research are:

- Carry out a literature review on all aspects related to the key elements of Eco-design, WEEE and RoHS directives.
- Identify critical issues affecting ECO-design implementation by way of a comprehensive questionnaire taking advantage of the literature review and available empirical research in the field.
- Carry out a detailed quantitative analysis on the data collected from the questionnaire.
- Develop a framework for Eco-design implementation, which helps to take into account WEEE and RoHS directives to produce environmentally friendly products.
- Conclude and recommend research for further work.

1.4 Scope of the research

In this research, a Plan-Do-Check-Act framework for eco-design implementation has been developed, based on the critical issues and activities affecting the contributing to Eco-design.

1.5 Structure of the research

This research in to seven chapters as follows:

Chapter 1

This first chapter presents an overview of the entire research. It highlights the challenging facing this research, its aims, objectives, scope and structure of the research.

Chapter 2

This chapter presents first a comprehensive literature review about WEEE and RoHS directives, then second a comprehensive literature review of Eco-design related issues and activities.

It starts with an introduction about the interaction between humans and the environment and what sort of challenges and impacts it produces, and presenting essential back ground information about Eco-design including: Eco-design definition, tools, some general consideration in Eco-design, principles of Eco-design, environmentally conscious design and manufacturing, design for environment.

In addition, other important issues related to product design and development such as materials and energy use and management are presented and explained.

There are information about WEEE and RoHS definitions and source of WEEE.

Chapter 3

This chapter discusses the research design and methodology used in the research, which adopts both descriptive and exploratory approaches as non-experimental cross sectional design methods. The aims and main steps in these two studies are discussed. Focus in the research strategies is directed on the quantitative questionnaire survey with a purposive sampling as the dominant methodology that combines with the qualitative approach namely the literature review. The rationale for the chosen triangulation design is also highlighted. It is worthwhile noting that statistical analysis using SPSS software is used in the data analysis in this thesis. The following is a summary of the chapter contents.

It starts with presenting the research process in general including the main stages of the research process. Research types are presented and explained in some details based on its two main types of quantitative and qualitative research approaches. Comparisons between the two main research approaches are provided. Triangulation is presented as another research approach combining both quantitative and qualitative research approaches, which is employed in order to overcome the weaknesses of the these two research types. Research methods namely literature review, case study, surveys including both interviews and questionnaires, and focus group are presented with emphasis on questionnaires. Questionnaires, developments are presented in terms of types, response sets, steps of questionnaire construction and finishing off with weaknesses and strengths of questionnaires. Explanation of research design and methods selected are explained in terms of different phases with an assistance of a flowchart. Questionnaire development is presented and discussed. The author's critique of the research approach chosen is presented and the chapter finishes with a summary.

Chapter 4

This chapter present the descriptive data analysis of the high-level activities and issued affecting Eco-design programme and WEEE directive implementation. The results of these analyses are discussed and key findings are reported. Questionnaire data summaries, categories and analysis are used to answer the research questions. Ranking ordinal data is discussed and consequently mode, median, and inter-quartile range are selected in order to measure variability and spread in the data analysed. The justification of this choice is discussed and the author's critique on ranking ordinal data is presented. Discussion about the justification of the scale used in the questionnaire is given. The rest of the chapter is dedicated to the data analysis results of motivators and barriers to Eco-design, Eco-design management system, environmental legislations, and Eco-design tools and considerations. A discussion about each of the above is given and the chapter finishes with a summary.

Chapter 5

In this chapter the developed framework for integrating WEEE directive by implementing Eco-design is presented.

The framework is based on the PDCA (Plan-Do-Check-Act) improvement cycle. An explanation of the cycle is given along with rational behind using as a basis for the suggested framework after comparing it with other traditional process and framework diagrams. A description and overview of the proposed PDCA Eco-design framework is presented along with its critical factors.

The framework together with the implementation plan provides a guiding force for companies to implement Eco-design on solid basis, which provides both guidance on how to design environmentally products and integrate WEEE programme into the business's normal operation and strategy, rather than on bits and pieces here and there and risk losing focus.

Chapter 6

This chapter provides the final conclusions and recommendations.

CHAPTER 2 LITERATURE REVIEW

Globalization of economy is a reality that every region, country and company is facing. One of the globalization's points of view is environment that strongly depends on industries' behaviour and the utilization of natural resources. In fact, management has more social responsibilities because environment is a public good. Consumers and ecological lobbies are requiring companies to implement cleaner production processes and green products (Sarmento, 2005).

The manufacturing industry has been accused of operating a system that takes, makes and wastes, although it also has the potential to become a creator of products that generate ecological, social and economic value. One possible way to improve on this viewpoint is for industry to embrace the "eco-efficiency" approaches; this might involve the adoption of "Design for Environment" or "Eco-design" techniques (Knight, 2008).

Today it is widely acknowledged that companies need to reduce the environmental impacts resulting from their activities. In the early days of industrial environmental consciousness, the focus was on so-called "end-of-pipe" solutions, i.e. solutions aimed at reducing the amount of harmful emissions and substances from manufacturing facilities. This has recently shifted to a focus on the products' environmental performance, reflecting a shift towards a more preventive approach in which focus is on the causes of the environmental problems, i.e. the products. Consequently, environmental considerations in product development should be viewed as an important part of the environmental concern of the companies, since product development merges current markets, technology trends and regulatory demands in to product features (Johnson, 2002).

In the following sections and based on the literature review, the author presents a general introduction about the environment and implications of neglecting it and overusing non-renewable natural resources such as materials and energy. Then, various aspects of Eco-design would be presented and discussed, and clear information about WEEE and RoHS directives

2.1 Humans and the environment

From the beginning of recorded time, humans have seen themselves as subduers of the earth, with dominion over all living things. Unfortunately, we have tended to interpret this as permission to take what might be taken, rather than seeing ourselves as responsible stewards of the planet on which we live. Our rapid technological development has caused serious environmental impacts that are the result of irresponsible way of living (Ljunberg, 2005).

Over the last few years, environmental issues have entered into policy design, particularly development and growth policies. Natural resources are considered necessary production inputs and environmental quality is considered a welfare determinant (Costantini, 2007).

Traditionally, process design has been guided by technical and micro-economic decision criteria to ensure that plants are “fit for purpose” and that the financial returns are maximized. However, it is now becoming increasingly obvious that modern plants can no longer be designed using these two types of considerations alone and that the other three dimensions of sustainability, environmental and social must also become an integral part of process design (Azapagic, 2006).

According to the European Commission, the total amount of waste (WEEE) in Europe expected to increase by about 45% between 1995 and 2020. At the same time this also means that the amount of waste of electrical and electronic equipment will continue to increase in the coming decades, and the environmental impacts of this waste will become more serious (Holden, 2008).

According to McAloone (McAloone, 2000), Mankind has been designed products for many ages; stone-age tools provide a clear evidence of man's ability to craft a product out of the need for a function. As the human race has developed we have begun to enjoy many benefits from our ever-increased ability to find solutions to our needs. It is only recently, however, that we are becoming aware of the effect that our consumption is having on the environment, and that many of the materials that we are using are not of an infinite source. In the last thirty years an emergency has started to arise, as the world's population continues to increase at exponential rates and so places more demands on the world's ever-diminishing resources.

The recognition of these issues has built up over recent years and pressures have slowly gathered momentum to keep attention of policy maker.

2.1.1 Sustainable Development

The earth's resources are limited. With the explosion in world population and the increasing rate of consumption, it will be increasingly difficult to sustain the current quality of life on earth if serious efforts are not made now to conserve and effectively use the earth's limited resources (Madu, 2001). It is projected that the current world population of 5.6 billion people at 2010 would rise to 8.3 billion people by the year 2025 (Furukawa, 1996). This is an increase of 48.21% from the current level. Yet the earth's resources such as fossil fuel, landfills, quality air and water are increasingly being depleted or polluted. Since the mid 1980s, we have witnessed a rapid proliferation of new products with shorter life cycles. This has created tremendous wastes that have become problematic as more and more of the landfills are usurped (Madu, 2001). In more recent publications, population growth has been predicted to double in the next 50 years to 9 billion. Typical growth in the UK is 0.3%, compared with 70% growth over the last two decades in China (Howarth and Hadfield, 2006).

Thus, and according to the author, the ecological equation has to be balanced, in order for the life of coming generation to be sustained and enjoyed in an acceptable and decent manner.

The balancing of the ecological equation is not a pure mathematics but rather a journey to achieve less and less negative impact on environment in every activity that is taken to produce any product through the whole life cycle of that product. The dream goal should be zero waste or zero negative impact, and any progress made towards that goal is most definitely a great contribution on the road to zero waste and sustainable production and consumption.

Consumers are becoming more and more aware of the damage being inflicted on the environment. Thus, the forming of environmental activist groups supported by consumers are putting pressures on corporations to improve their environmental performances. The increase of new environmental legislations, directives and standards such as WEEE (Gottberg et al., 2006), RoHS (Anon., 2004) and ISO 14000(Environmental Management System) (Ghisellini and Thurston, 2005, MacDonald, 2005) group of standards have been forcing the way to implement sustainable development.

The origins of sustainable developments can be traces to the United Nations publication in 1987 titled the Bruntland Report. This Report is named after Mrs.Bruntland, Prime Minster of Norway who chaired the UN World Commission on Environment and Development. The report focused on the problems of environmental degradation and states that "the challenge faced by all is to achieve sustainable world economy where the needs for the entire world's people are met without compromising the ability of the future generation to meet their needs".

Since its publication, the world community has convened conferences on how to achieve sustainable developments. In 1992, the UN organized the Earth summit in Rio De Janeiro, Brazil with a focus on how to get the world community to cut down on the use of non-renewable resources in order to achieve sustainable development. Several publications have emerged on sustainable development since the conference (Madu, 2001, Sibbel 2007).

The efforts to develop sustainability indicators have strongly increased since the beginning of the 1990s, often led by intergovernmental process. More recently, a number of sustainability indicator development processes have been initiated within large research projects that aim to design tools for sustainability assessments, funded by the European Union (Rametsteiner, 2009).

There are a number of definitions of sustainable development (SD), each with a different focus depending on the purpose of the study. A precise and commonly accepted definition of SD is defined as economic development with higher economic benefits and better ecological performance. The ecological performance of economic development includes two aspects resources-energy consumption and environmental pollution. Better ecological performance means lower recourses-energy consumption and less environmental pollution (Xu, 2005)

A sustainable product is a product, which will give as little impact on the environment as possible during its life cycle (Ljungberg, 2007).

The life cycle in this simple definition includes extraction of raw materials, production, use and final recycling (or deposition). The material in the product as well as the material used for producing energy is also included here. This definition is in fact not totally defined according to the amount of impact on the environment or the nature. Hence the impact cannot be zero, it must be ‘reasonably minimised’. This opens the fact that there will be similar products, which are more or less ‘sustainable’ when they are compared side by side (Ljungberg, 2007).

It is paramount and a prerequisite that any sustainable product should be a successful product, which satisfy users’ need and requirements and completely fits the purpose it was designed for. There are estimations, which tell us that nearly 90% of all technology good products will not be a success on the market for various reasons (Patrick, 1997).

When releasing sustainable products on the market, it is reasonable to believe that the risk for failure is not less. It is important to inform people as to what basis a certain product is considered to be sustainable or not and why they should buy it. However the demand for producing environmentally products are not clear and easy to understand for general customer. Even for an expert it is problematic or impossible to determine which product of many similar ones is the best choice (Ljungberg, 2007).

Designing sustainable products, which contributes directly to balancing the ecological equation is the main objective of this research. The term Eco-Design will be used throughout this work to represent designing sustainable products, taking into account the WEEE and RoHS directives from the first step in designing the product.

2.1.2 Motivations for sustainable development

The number of motivators for the industry to implement sustainable development, and design environmentally friendly products is (McAloone, 2000):

- Legislation as it forces companies to implement environmentally friendly practices in order to stay in business and avoid hefty fines, such as WEEE and RoHS directives.
- Competition
- Consumer pressure

In the following sections are explanations of these three main motivators for the industry to act upon.

2.1.2.1 Legislation

The environmentally related legislations cover a wide range of design, manufacturing, and disposal matters. Two major EU programs most directly affect sustainable products in Europe:

- The EU Eco-label
- EU initiatives on packaging, recycling and waste reduction

As a member of the EU, the United Kingdom has already established an authority for awarding the EU Eco-label. Britain is also moving forward on domestic packaging waste reduction measures (Cattanach et al., 1995). However, the UK government's overall approach to eco-labelling fits with the national environmental regulatory style, which has often been characterized as a pragmatic ("trial and error" driven) and consensual search process for the most cost efficient environmental options (Jordan, 2002, Wurzel, 2002). The British government's stance on Eco-labels has been devoid of a grand strategy and characterized by a multitude of relatively small scale initiatives (DEFRA, 2002).

Another major EU programme relating to the environment is the (WEEE) directive. Electrical and Electronic Equipment is regulated by the WEEE Directive (2002/96/EC) if it uses a voltage less than 1000 V for AC and less than 1500 V for DC (including battery powered). WEEE directive, to be implemented in stages from 2004, attempts to tackle the growing quantity WEEE by making producers responsible for the costs of the collection and recycling of their products at the end of usable life (Darby and L., 2005, Gottberg et al., 2006, Widmer et al., 2005).

The WEEE Directive required that all EU countries have national implementing legislation in place by 31 August 2004. The UK postponed implementation several times. In mid 2005 the EU finally lost patience with the delay and issued a formal notice to the UK requesting an explanation for the delay. After several false starts, the UK's Department of Trade and Industry (DTI) released its final consultation paper in late July 2006("the final draft regulations") announcing the commencement of the implementation on 1st January 2007, but not all provisions came into force until 1st July 2007 (Turner and Callaghan, 2007).

The European Union (EU) (RoHS) Directive (2002/95/EC) prohibits the use of certain substances such as lead and mercury in electrical and electronic equipment from 1st July 2006 (Cusack and Perrett, 2006, McCluskey et al., 2006).

The ELV Directive (End-of-Life Vehicle Directive) is another important directive, which limits the amount of polluting metals contained in vehicles in order to minimise the pollution hazards caused by recycling of their components (Ruhland and Casey, 2006).

In addition to the above legislation, there are much other legislation such as the phasing-out of ozone-depleting gases such as CFCs (chlorofluorocarbon is an organic compound contains chlorine, fluorine and carbon) starting in 1992, the introduction of packaging laws in Germany in 1991, the introduction of landfill levy in the UK in 1995 and so on and so forth (McAloone, 2000).

According to Mackenzie (MacKenzie, 1991), increasing public support has led to demands for more legislation to control industrial activity. The extent of legislation varies considerably between countries, and even within parts of a country, but there is universal belief that the amount of legislation will increase. Meeting new legislative demands such as these will require significant changes, and will change priorities especially in areas such as product design

2.1.2.1.1 WEEE Directive

On 11th October 2002, the draft version of the (WEEE) was agreed in a conciliation meeting between the European council and parliament. This was almost certainly the final version, since changes after this stage are very uncommon. The timetable was expected to be as follows (Clark, 2002, Harding, 2004 and Envirowise, 2005):

Directive passed in to European Law:March 2003

On the UK Statute Book:September 2004

Financial aspects of producer responsibilitySeptember 2005

At least 1 million tonnes of WEEE from domestic and commercial sources is discarded in the UK every year and it is estimated that this waste stream is growing by 4-8% a year (Harding, 2004).

The purpose of the directive is, as a first priority, the prevention of (WEEE), and in addition, the reuse, recycling and other forms of recovery of such wastes so as to reduce the disposal of waste. It also seeks to improve the environmental performance of all operators involved in the life cycle of electrical and electronic equipment, e.g. producers, distributors and consumers and in particular those operators directly involved in the treatment of WEEE (Clark, 2002).

The purpose of this directive is to approximate the laws of the Member States on the restrictions of the use of hazardous substances in electrical and electronic equipment and to contribute to the protection of human health and the environmentally sound recovery and disposal of waste electrical and electronic equipment (Harding, 2004).

The European Commission proposed a directive on WEEE that mentions three objectives (Knoth et al., 2001):

- The prevention of waste;
- Increasing re-use, recycling and other forms of recovery;
- Minimizing environmental risks and impacts with the treatment and disposal of electronic products.

Scope

These Regulations apply to all electrical and electronic equipment placed on the market in the United Kingdom falling into any of ten categories, unless the equipment is part of another type of equipment, which does not fall into any of these categories. The Regulations also specify a voltage range into which products in the ten categories must fall to be covered by the scope. This is up to 1.000 volts AC or up to 1.500 volts DC (DTI, 2004, Pb-free, 2004).

The directive applies to suppliers of relevant equipment, and, by implication, applies indirectly to suppliers of components and assemblies. It is not yet clear whether the Directive will apply directly to suppliers of components and assemblies (Clark, 2002)

The clause from the previous version that would have allowed national governments to exempt small companies from having to satisfy the directives requirements has been removed in the final version.

Definition

It defines electrical and electronic equipment, which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields. The ten product categories are:

1. Large household appliances; such as large cooling appliances, refrigerators, freezers, washing machines, clothes dryers and dish washing machines.
2. Small household appliances; such as vacuum cleaners, toasters, fryers, grinders, clocks, scales, irons and hair dryer.

3. It & telecommunications equipment; such as laptop computers, printers, personal computers, notebook computer, notepad computers, copying machines, telex and telephones.
4. Consumer equipment; such as radios, televisions, video cameras, video recorders, musical instruments, Hi-Fi recorders, audio amplifier and any other product for the purpose of recording or reproducing sound or images.
5. Lighting equipment; such as straight fluorescent lamps, compact fluorescent lamps, luminaries for fluorescent lamps and any other equipment for the purpose of spreading or controlling light.
6. Electrical and electronic tools; such as drills, saws, sewing machines and tools for welding or soldering.
7. Toys leisure and sports equipment; such as electric trains, car racing sets, video games and sport equipments with electric or electronic components.
8. Medical devices; such as radiotherapy equipments, cardiology, dialysis and nuclear medicines.
9. Monitoring and control instruments; such as smoke detector, thermostats and heating regulators.
10. Automatic dispensers; such as dispensers for hot or cold drinks, dispensers for solid products and dispensers for money.

Exceptions [44]:

The Regulation does not apply to:

- Equipment intended specifically to protect the UK national interest and for a military purpose, e.g. arms, munitions and war material
- Filament light bulbs
- Household luminaries
- Large-scale stationary industrial tools
- Implanted medical equipment and infected medical equipment at end-of-life

Components, sub-assemblies & consumables*:*

If components, sub-assemblies and consumables (e.g. batteries, tapes, and disks) are present in a product within the scope of the regulations at the time it is separately collected, they are subject to requirements of the Agencies' treatment guidance (DTI, 2004).

Guidance on specific exemptions:

- Products intended specifically to protect national security and for a military purpose- this exemption is interpreted to means equipment that has a specific application only in these fields, such as arms, munitions and war material. It does not apply to equipment, which is used to protect national security, and/or has a military purpose, but is not solely for these purposes.
- Filament light bulbs – this exemption applies to all light bulbs, which emit light through the use of a filament.
- Household luminaries - regarded as the immediate structure surrounding a lamp, including the lamp holder or socket with a standard three-pin plug and/or designed to take a light bulb together with other attachments fixing this to wall, or ceiling or body of a freestanding lamp. However, luminaries used in commercial premises are covered by the regulations.
- Large-scale stationary industrial tools- this is a machine or system, consisting of a combination of equipment, systems or products, and assembled to be used only in fixed industrial applications.
- Implanted medical equipment and infected medical equipment- applies to all medical equipment that has been implanted or has otherwise come into contact with blood or other biological contaminants prior to end-of life.

Other product types, which are deemed to be outside the scope of the Regulations:

The guidance that follows uses some of the criteria for assessing "grey area" products which have been discussed in the Technical Adaptation Committee (TAC) of Member States. It should be noted that this guidance represents a view from the Department of Trade Industry (DTI). Ultimately producers will want to take their own legal advice on questions of scope.

- **Products where electricity is not the main power source**

  Many products contain electrical and electronic components. An example might be an electric thermostat for a gas heating system. The regulations cover only those products dependent on electricity to function properly. In the above example the electric thermostat may be considered to be in the scope of the regulations, but the gas system may be considered to be outside the scope of these Regulations.

- **Products where the electrical or electronic components are not needed to fulfil the primary function**

  This is related to, but not always the same as, the above situation. Some products, particularly toys and novelty items contain an electrical or electronic element to give added value. Often there are similar products on the market fulfilling the same function, but without these components. Examples might include musical greetings cards. These products still fulfil their primary function without their electronic components and could be considered to outside the scope of the Directive.

- **Items which are part of another type of equipment or fixed installation**

  Equipment which is part of another type of equipment or system is considered to be outside the scope of the Regulation where it does not have a direct function outside the other item of equipment (e.g. a car radio).

  Equipment may also be a part of a fixed installation. A "fixed installation" may be a combination of several pieces of equipment, systems, products and /or components (parts) assembled and/or erected by professional assembler or installer at a given place to operate together in an expected environment and to perform a specific task. In such case, elements of a system which are not identifiable as electrical and electronic equipment in their own right or that do not have a direct function away from the installation are excluded from the scope of the Regulations.

Examples of products excluded from the Regulations

Using the criteria set above, it is possible to take a view as to whether certain “grey area” products are included or not under the scope of the Regulations;

- *Gas central heating with electric pumps, timers and controls*-the built in heating system is excluded, although the externally mounted monitoring and control equipment is covered, provided it can be separated from the main system.
- *Replacement computer hard drive* – excluded, this is a component or sub-assembly of a computer. However, peripheral hard drives sold, as separate equipment would be included in the scope of these Regulations.
- *Lighting equipment for use on aircraft*- this is designed to be part of an aircraft-which falls outside the scope of the Directive.

Sources of WEEE

End-of life electric and electronic equipment mainly originates the following three sources (Knoth, 2001):

1. Manufacturer, distributors and retailers.
2. Commercial end- user.
3. Domestic end-user.

2.1.2.1.2 RoHS

The disparities between the laws or administrative measures adopted by the member of states as regards the restriction of the use of hazardous substances in electrical and electronic equipment could create barrier to trade and distort competition in the community and may thereby have a direct impact on the establishment and functioning of the internal market (Pb-free, 2004).

Objectives

The purpose of this Directive is to approximate the laws of the Member of States in this field and to contribute to the protection of human health and environmentally sound recovery and disposal of waste electrical and electronic equipment (Pb-free, 2004).

Scope

This Directive does not apply to spare parts for the repair, or to the reuse, of electrical and electronic equipment put on the market before 1 July 2006 (Pb-free, 2004).

Member States shall ensure that, from 1 July 2006, new electrical and electronic equipment put on the market does not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE), on the prohibition of other hazardous substances and the substitution thereof by more environment-friendly alternatives which ensure at least the same level of protection for consumers.

The maximum concentration value of up to 0.1% by weight in homogenous materials for lead, mercury, hexavalent chromium, PBB and PBDE and up to 0.01% by weight in homogenous materials for cadmium will be permitted in the manufacture of new EEE, they will reviewed regularly (every 4 years) to discover if technical obstacles to their substitution have been overcome.

Homogenous materials is defines as a material that cannot be mechanically disjointed into different materials.

Penalties

Failure to comply with the requirements of the UK's RoHS regulations will result in the removal of manufacture's product from the market place.

In addition, those held responsible face, on summary conviction, a term of imprisonment not exceeding three months and/or a fine of up to £5.000. Where any offence is tried on indictment, the maximum penalties are a term of imprisonment of up to two years and an unlimited fine (Pb-free, 2004).

The concern is that too many of the discarded machines are ending up in developing countries to be dismantled in ways that are damaging to the environment and to the health of the workers who take those a part (Black, 2004).

All manufactures are now obliged to set up recycling schemes, but business remains responsible for implementing complaint disposal.

2.1.2.2 Ideal end-of-life management of electric and electronic products

Especially for electric and electronic products, there are several end of life (EOL) options existing, namely: upgrade, re-use, recondition, re-manufacture, and recycling of materials and disposal. In figure 2.1 it is shown which priorities from an environmental perspective generally apply (Knoth et al., 2001):

1. Re-use product as a whole. If a product is in good condition, it is refurbished and resold or donated to an organization, such as a school or charitable group.
2. Re-use some of the parts and components again in a new product, and if there are any working parts that have value should be sold.
3. Material recycling. Any remaining parts and materials from the disassembling process; such as precious metals, other metals, plastics and so forth are separated into discrete streams. Streams that have value – which means that it is present in a quantity and quality sufficient to interest an end market-undergo further processing for material recycling. That may include shredding, granulating, washing and/or further identification and separation.
4. And 5. Incineration and disposal. The remaining streams are covered in an incineration facility or disposed in a landfill.

Re-use and recycling in electronic industry is a very demanding but advantageous alternative to incineration or the landfill of electronic scrap. Thus the market for re-use and recycling has a growing interest for companies. This followed any increasing research and development activities especially for technological solutions.

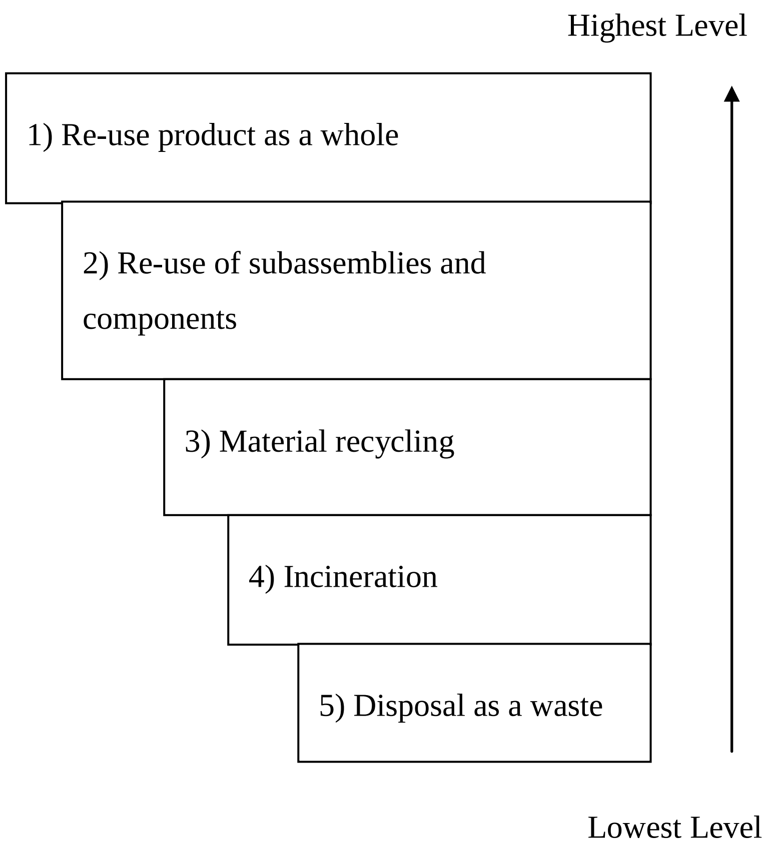


Figure 2-1Hierarchy of end-of-line options

2.1.2.3 Competition

Historically competition always has and still plays a major part in product design and manufacturing as it is a main driver behind new innovations and improving product performance in all aspects. Improving environmental performance of any product would most likely trigger the same reaction by the competition and in turn that would result in an environmental continuous improvement cycle. Moreover firms are becoming aware of the potential link between technological dynamism, economic success and better environmental performance (Berkout, 1995).

In this day and age, consumers are becoming more and more aware about the benefits of buying and using environmentally friendly products, which in many cases would save them in cost. For example the energy saving light bulbs and the energy rated white goods such as washing machines and fridge-freezers. The increasing competition and the need to identify new profit centres for producers of mature products such as baby prams has led to a new business model for baby prams based on leasing and product remanufacturing using Eco-Design principles (Mont et al., 2006)

The automotive industry is highly driven by competition and the environmental attributes in designing cars are becoming very significant, especially with increasing legislation regarding recycling, fuel consumption, CO2 emission, etc.

In a report by the Open University (McAloone, 2000), 50% of the companies surveyed confirmed that their ‘green’ products were more competitive than their non environmentally designed predecessors. In addition to reducing the fuel consumption, the competition could be on prolonging the life of cars, which could reduce the overall environmental burden (Spielmann and Althaus, 2006).

2.1.2.4 Consumer Pressure

The environment is an increasingly important issue for marketers in all areas of business. Consumer demand for more environmentally friendly products (green products) is growing, as is pressure for legislation requiring industry to “clean up its environmental act”. This combined opportunity and threat has led marketers to acknowledge that the green challenge will force business to change dramatically. Companies are scrambling to generate or regain competitive advantage by proving their green credentials, and to back up their green rhetoric with improved environmental performance (Peattie and Ratnayaka, 1992, Vandermerwe, 1990).

In Europe and the United States, concerns for the environment have become one of the most important issues of the 1990s. Companies have discovered that consumers will buy products, or avoid purchase, based upon environmental considerations. This phenomenon, referred to as Green Marketing, involves marketing response to the design, production, packaging, use and disposal of products (Lampe and Gazda, 1995).

A good example of consumer pressure is the renewable energy market namely electricity. In the United Kingdom, the energy supply market is completely privatised and there are a considerable number of energy suppliers competing directly for business, it is found that a growing number of customers are opting to buy from suppliers offering electricity generated from renewable sources such as wind turbines and in some cases paying a premium. The green electricity phenomena and the energy efficiency on the whole have become the focus of new legislations and investments especially in Europe (Arkesteijn and Oerlemans, 2005, Kristina, 2005, Nilsson, 2007, Salmela and Varho, 2006).

2.2 Environmentally conscious Manufacturing (ECM)

ECM is also called environmentally conscious process design ECD can be described as "the deliberate attempt to reduce ecological impacts of industrial activity without sacrificing, cost, reliability, or energy utilisation efficiency" (Zhang and Kuo, 1997).ECM is also called green manufacturing(Hui et al., 2001, Madu et al., 2002, Pal, 2002).

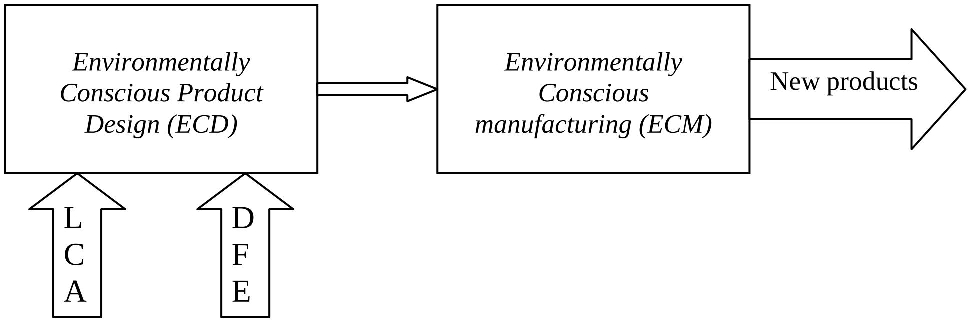
Thus activities of ECM emphasize largely extracting the useful product from raw material, the avoiding of waste generation at source, or using waste to create other products. In addition, ECM involves refining operating procedures, replacing existing processes and developing new, waste free processes, finding innovative ways to redesign products, and increasing recycling.

According to the literature, the ECM consists of all the following key issues (Cattanach et al., 1995, Gungor and Gupta, 1995, Madue et al., 2002):

- Understanding the life cycle of the product and its impact on environment at each of its life stages.
- Making better decisions during product design and manufacturing so that the environmental attributes of the product and manufacturing processes are kept at desired level.

The first issue is necessary for drawing lines to determine how the product will evolve from the drawing board and how it will affect the environment throughout its life stages. If we fully understand the life cycle of the product, we can transfer this information on to the actual development of the product (which addresses the second issue of ECM). In addition, understanding the end-of -life (EOL) stage of the product is critical since one of the largest impacts on the environment occurs at that stage.

During the design stage of the product, there are different objectives that the designers may focus on. Depending on the end-of-life strategy of the product, the design of the product can be realized to increase recycle-ability, manufacturability, and disassemble-ability and minimize the effect on the environment. When designing a product with environmental features, material selection should also be considered as a key element.



LCA (Life Cycle Assessment)

DFE (Design for Environment)

Figure 2-2Environmentally Conscious Manufacturing (Gungor and Gupta, 1995).

In order to have a successful implementation of ECM, it is important to have a comprehensive knowledge and understanding of the product life-cycle undergoing ECM programme. The following section provides a brief explanation.

2.2.1 The product life cycle

The life cycle of a product is understood to be the stages that the product goes through from conception through embodiment and use, and finally to disposal – or 'from cradle to grave'. A product life-cycle embraces a number of issues including design, manufacturing, assembly, testing, shipping, distribution, operation (use), services, reuse, re-manufacturing, recycling and disposal (Ayers, 1995, Gu and Sosale, 1999, Guinee et al., 1993, Ljungberg, 2007).

According to McAloone (McAloone, 2000), the product life-cycle has been represented in many ways, but the definition that carries the most authority is that of the Society of Environmental Toxicology and Chemistry (SETAC), the world leading life-cycle analysis (LCA) authority. SETAC's representation of the product life-cycle is shown in Figure 2.3.

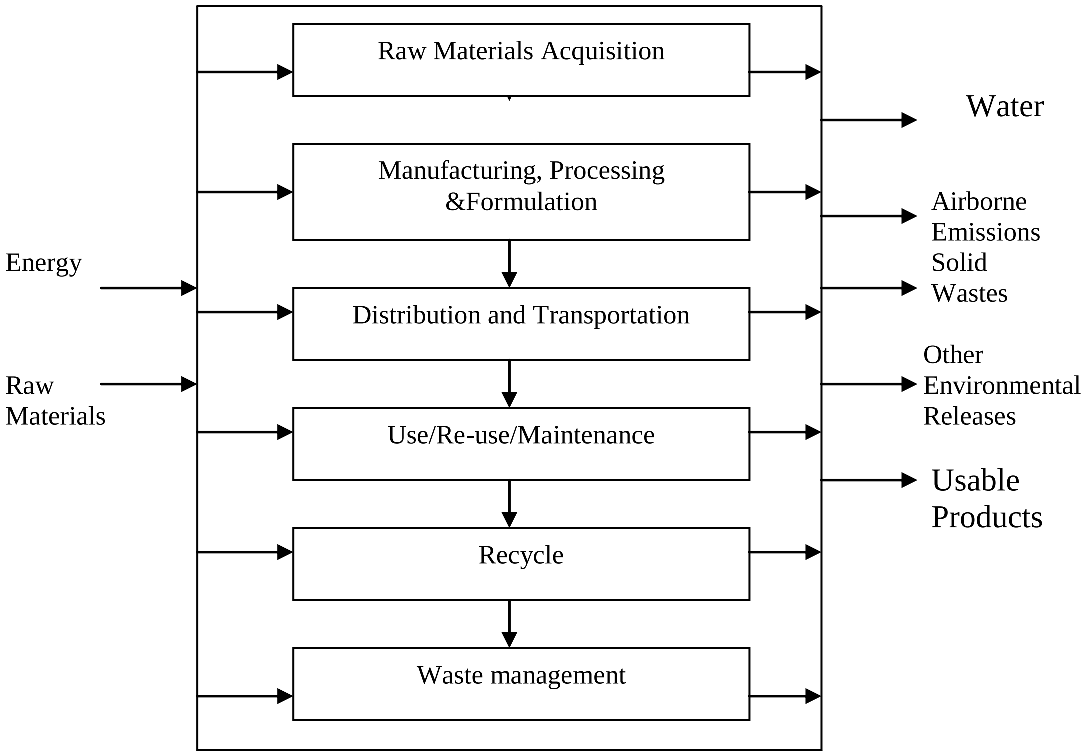


Figure 2-3 Product life-cycle (McAloone, 2000)

2.2.2 Environmentally Conscious Design (ECD)

ECD, also known as Eco-Design or green design, is a discipline which aims at reducing the environmental impact of products, by reducing energy and resources consumption, solid waste and pollution throughout the whole product's life, and particularly by making them easier to dismantle, recover and recycle (Bernasconi et al., 2007, Cohen, 2006, English et al., 2006).

Two different strategies for integrating environmental concerns into new product and process design will be investigated. Design for the environment (DFE) is the less rigorous of the two methods and generally can be quickly and easily adopted by a company's design group. Life cycle analysis (LCA) is an extremely in-depth process that is still in its infancy. All the tools and databases required to fully implement LCA are not currently available. The concepts that underpin LCA can be used on smaller scale by providing the proper design tools and training (Cattanach et al., 1995).

According to Gungor and Gupta (Gungor and Gupta, 1999), who carried a comprehensive literature review about ECD and to the author's own detailed review; ECD puts a great emphasis on both life cycle assessment (LCA) and design for environment (DFE). The following sections discuss LCA & DFE.

2.3 Life Cycle Assessment LCA

LCA is a process for assessing and evaluating the environmental, occupational health and resource consequences of a product through all phases of its life, i.e. extracting and processing raw materials, production, transportation and distribution, use, remanufacturing and final disposal (Gungor and Gupta, 1999).

LCA, also known as cradle-to-grave assessment and eco-balancing, is a technique to examine the environmental impact of a product life cycle in every conceivable area, from the choice of raw materials used to its return to the earth as waste (Kimura et al., 2001, Mila i Canals et al., 2006, Rebitzer et al., 2004, Wilks, 1999). The following are examples of LCA applications:

- LCA was used to evaluate the environmental consequences of computer display technology substitution (Zhou and Schoenung, 2007).
- LCA framework was used to develop a building environmental performance analysis system (BEPAS)(Zhang et al., 2006).
- LCA was used to assess the environmental performance of different operating conditions of micro-filtration membrane (MF) process (Tangsubkul et al., 2006).

- LCA was used to conduct a comprehensive comparison of fuel options for fuel cell vehicles in China (Wang et al., 2005).
- LCA was used in the life cycle of alternative coffee packaging (De Monte et al., 2005).
- LCA was used to identify environmental 'hot spots' in a reference product's life cycle and to select new environmentally optimised solutions for a new product (Nielsen and Wenzel, 2002).

LCA is a decision support tool supplying information on the environmental effects of products and processes. It furnishes information on environmental effects of all stages of a product's life cycle (Zhang et al., 1999).

LCA is a technique for tracing out all the environmental effects and resource needs of a new product or process through the material suppliers, through manufacture, use and disposal. It is intended to provide a comprehensive assessment of environmental effects (Hendrickson et al., 1999).

The purpose of LCA is to determine the environmental impacts of a product, product group, system, process, or action as comprehensively as possible. It aims to identify weaknesses, ecological improvements; support decisions promote environmentally friendly products and methods, compare alternative ways of behaviour and legitimising recommendations for action with regard to environmental impacts of those actions (Tischner et al., 2000).

2.3.1 The steps involved in LCA

During the survey of literature, the steps of LCA that are repeatedly mentioned are as follows (McAloone, 2000, Gungor and Gupta, 1999, Wilks, 1999, Zhang, 1999, Hendrickson et al., 1999, Lindhal, 2001, Jean, n.d., Brezet et al., 1999, Wetiz et al., 1996):

- Identification of the goals and boundaries of LCA (defining system goals and boundaries).
- Analysis of inventory to achieve a balance between material and energy in the system (carrying out an inventory of all the materials and energy used and all the

environmental discharges resulting from the product's manufacture, use, and disposal within the defined boundary). This step could be titled Life-Cycle Inventory (LCI).

- Evaluation of the system's impact on the environment according to the ISO14040 standard (carrying out an assessment of the environmental implications resulting from the discharges and materials use identified in the inventory). This step could be titled Life-Cycle Impact Analysis (LCI).
- Assessment of the most promising system improvements to reduce the negative environmental impact (carrying out an assessment of the opportunities for improvement). This step could be titled Life-Cycle Improvement Analysis.

Advantages and disadvantages of LCA

To be able to use the LCA method efficiently there is often a major need of quantified data. It is first after having for example decided which materials and how much to use that the LCA can be made. At this stage the conceptual design phase is most often already completed and thus the design freedom limited.

A properly performed LCA on a product or service can have the following advantages:

- Accurate and acceptable results if traditional LCA is performed.
- Reveal down-and upstream impacts, which otherwise would remain hidden.
- Generate new ideas for providing the same function with reduced environmental impact.
- Clarify environmental controversies.
- Be useful aid decision making in the product development team.

Although LCA is often performed properly, there are also several obstacles and problems. The method has therefore been criticised:

- LCAs often make different assumptions about system boundaries and relevant data (The main problem with LCA have arisen so far when separate organizations have drawn different system boundaries for similar products and so have to collected and analysed inconsistent types and quantities of data, leading to difficulties when attempting to compare results).
- To make an LCA on a new product or process is difficult and expensive.

- LCA is too expensive and slow for application in the design process.
- Demands a lot of education to be used in proper way.
- Data quality is not uniformly high. A small change in input data may cause significant variations in the result.
- There is a lack of comprehensive data for LCA.
- Equally credible analyses can produce qualitatively different results.
- It is a comparative rather than absolute tool therefore only very similar products can be effectively appraised.
- Determining which environmental issue assumes priority is framed by geographical social and factors and often raises more questions than answers.
- There is no single method that is universally accepted.

These issues leave companies unconvinced about the amount of time and effort required to carry out an LCA on a product, next to the usefulness of the results to any audience other than themselves.

2.4 Environmentally Conscious Production (ECP)

ECP is also referred to in the literature as sustainable production, environmentally friendly production or cleaner production (Cauffiel and Porter, 1996, Cristina da Costa et al., 2000, Morrow et al., 2007, Narayanaswamy and Stone, 2007, Scavone, 2006, Srinivasan and Sheng, 1999).

According to the Lowell Centre for Sustainable Production, ECP or sustainable production is creating goods by using processes and systems that are non-polluting, that conserve energy and natural resources in economically viable, safe and healthy ways for employees, communities, and consumers and which are socially and creatively rewarding for all stakeholders for the short and long term future (Lowell Center for Sustainable Production, 2005).

2.5 Eco-Design

Eco-Design is the second element of ECD besides LCA.

The terms DFE, Eco-Design, sustainable design, green design, etc. do actually mean the same thing and in essence all of these terms refer to designing products which have less impact on the environment (Donnelly et al., 2006, Lewis et al., 2002, Luttropp and Lagerstedt, 2006, Nakamur and Kondo, 2006, Pujari, 2006, Recher, 2001, Stevels, 2001, Sundin and Bras, 2005). In this work, the author is using the term Eco-Design instead of *DFE.* Switching between the terms Eco-Design and DFE is taking place through the course of this work due to the different references the author is using.

Eco-design means environmentally conscious product development and design. Eco-design directly expresses the fact that Ecology and Economy must be joined inseparably by means of good design in Eco-design procedures (Tischner et al., 2000).

This means that "environment" is added as a criterion of product development alongside other classical criteria of functionality, profitability, safety, reliability, ergonomics, technical feasibility, and last but not least aesthetic. The term Eco-Design directly expresses the fact that ecology must be joined inseparably by means of good design in Eco-Design procedures. Put in brief: Eco-Design leads to "products, systems, infrastructures and services, which require a minimum of resources, energy and land area to provide the desired benefit in the best possible way while at the same time minimising pollutant emissions and waste arising over the entire life cycle of the product. In addition, Eco-Design fits into the concept of "sustainable design" which is closely bound up with the image of Sustainable Development (Tischner et al., 2000).

2.5.1 Eco-Design golden rules

During the survey of literature, the author identified rules of thumb, guidelines or golden rules for Eco-Design. These rules can be characterized as the result of life cycle thinking, and work rather like a compass for Eco-Design practitioners to guide and remind them about the essence of any Eco-Design programme. The following is a list of these rules (Clark, 2002, Stevels, 2001, Thompson, 1999):

- Ensuring any assessment of a product's environmental compatibility must include its whole life cycle. The analysis should be from 'cradle to grave'.
- Ensuring the intensity of processes, products and services has to be reduced drastically.

- Ensuring the material intensity of processes, products and services has to be reduced by a factor of 10 and the productivity of resources increases accordingly.
- Ensuring the energy intensity of processes, products and services has to be reduced by a factor 10 and the productivity of sources increased.
- Ensuring the land use per service unit has to be minimised and the productivity of sources increased.
- Ensuring the emission of hazardous substances has to be eliminated.
- Ensuring the sustainable use of renewable resources has to be maximised.
- Ensuring to benchmark all of the above against the best similar eco-products available where possible.

2.5.2 Eco-Design drivers and impediments

In this section the author is presenting both drivers and impediments to Eco-Design implementation. The most important and popular drivers (motivators) and impediments (barriers) are discussed in the following subsections.

2.5.2.1 Eco-Design drivers

Eco-Design is the tool for developing and producing sustainable products, so the motivations for sustainable development in section 2.1.2 would also apply for Eco-Design. However, the main drivers for Eco-Design are illustrated in the so-called green circle of Eco-Design activities as shown in Figure 2.4.

The drivers can be specified as follows:

- Customer requirements: Fulfilling or even exceeding such requirements will substantially enhance the success of Eco-Design. This became first apparent in the original equipment business, where OEM’s like computer companies have nowadays-green requirements lists for vendors. Private consumers generally have fairly indistinct ideas about green product aspects but organizations working on behalf of them like consumer unions have currently a green paragraph in their product ratings. Institutional customers are a strong force in several markets and their demands (for instance to supply eco-labelled products) have a corresponding influence.

- Legislation, regulation: Although relatively little legislation/regulation is yet in place, this field develops fast. Subjects include:
  a. Regulation on energy consumption of products (standby and operational mode).
  b. Restriction on substances (heavy metals, frame retardants, ozone depleting chemicals).
  c. Take back and recycling obligations (i.e. the WEEE directive in the European Union).
  d. Environmental conformity requirements in general (i.e. the draft EEE proposal of the European Union).
- Cost, money: Around 1995 it was realized that for many product categories, ecology and economy were running rather opposite than parallel.
- Quality: Eco-Design calls for frugal, simple fulfilment of the required functionality. This results in product concepts which consist of simpler components and subassemblies and which have simpler architectures. These are easier to produce and show less rejects.

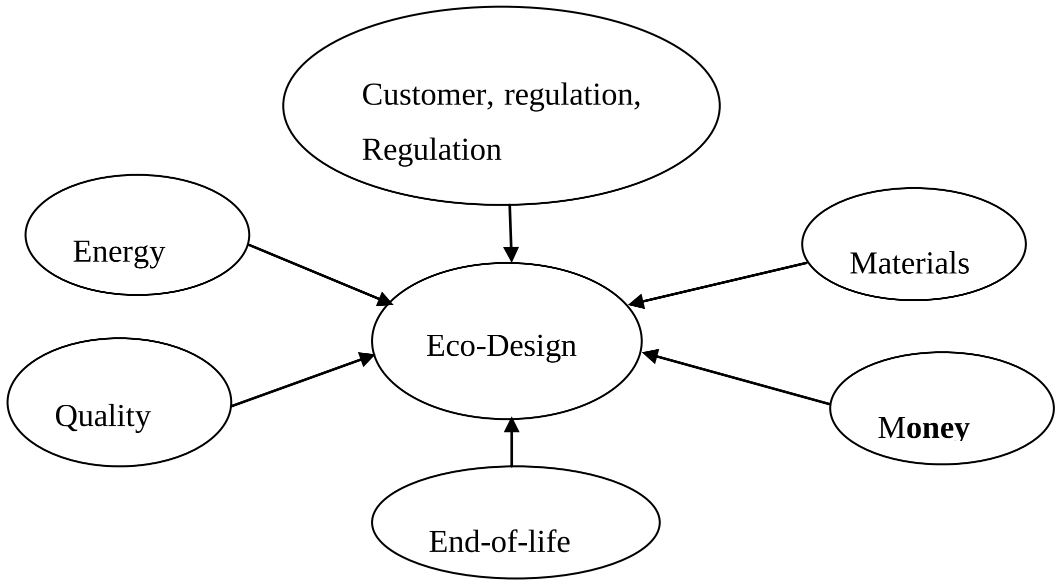


Figure 2-4the green circle of Eco-Design activities adopted from (Stevels, 2001).

In addition to the above drivers (motivators) for Eco-Design, the author during the course of this work identified other motivators, which are as follows (Ammenberg and Sundin, 2005, Bailey and Rupp, 2005, Ball, 2002, Beise and Rennings, 2005, Berkel, 2007, Van der Zwan and Bhamra, 2003, Van der Zwan and Bhamra, 2003):

- rising disposal costs;
- increased taxes;
- publicity/image;
- pressure from employees;
- meeting requirements of customers/local suppliers;
- meeting trade/international trade requirements;
- satisfying interest groups;
- pressure from industry organisations;
- actions of non environmental organisations.

2.5.2.2 Eco-Design impediments

In the design and manufacturing sector, resistance to new design, new manufacturing strategies and techniques is very strong. The main problems are lack of belief in promised benefits and fear of extra cost. The main impediment and killer to any Eco-Design initiative is the lack of top management commitment. If top management commitment is secured and a strong leadership for Eco-Design is established, other barriers to Eco-Design could be resolved. The most popular barriers to Eco-Design, which are reported in the literature, are as follows (Ammenberg and Sundin, 2005, Boks, 2006, Chick and Micklethwaite, 2004, Van Hemel and Cramer, 2002)**:**

- No top management commitment and willingness.
- Cynical attitude to adopting alternative design methods namely Eco-Design.
- Accepting excessive waste as a necessary by-product of manufacturing.

- Existing equipment and technology at manufacturing are not compatible with Eco-Design.
- No new investment in equipment and technology.
- No believe in the organisation that with existing equipment and technology available at the manufacturing plant, Eco-Design products could be produced.
- Fearing of extra cost without any tangible benefits.

2.5.3 ISO 14000 family of standards

ISO 14000 emerged in 1996 and was developed by an independent organization of the International Standard Office (ISO). It is a formal, certified quality system, consisting of a series of guidelines or processes to help direct a company's management to accept and acknowledge technical standards. It is believed that the adoption of this system can help management to create competitiveness by reducing costs in the manufacturing process and to inspire management to seek sustainable development through the design of green products and clean production processes. It is seen as an effective tool to create competitive advantages for firms by allocating resources to satisfy both the firm and the stakeholders (Chen, 2005, Abarca, 1998):

The new series of ISO14000 standards are designed to cover:

- Environmental management system
- Environmental auditing
- Environmental performance evaluation
- Environmental labelling
- Life-cycle assessment
- Environmental aspects in product standards

Furthermore, in designing the ISO 14000 specifications for an EMS, the intent was to create a generic model that could be applied by any type and size of organization throughout the world. The standards can be implemented within the whole organization or only in specific parts: they are not industry or sector specific. However it must be emphasized that implementation of a system alone cannot guarantee environmental excellence or even compliance. Furthermore, companies are not limited to the content of

ISO 14000 when implementing their EMS. These merely represent the minimal requirements for certification against the ISO 14000 EMS standard (Abarca, 1998, Curkovic et al., 2005). The following section discusses the relationship between Eco-Design and EMS.

2.5.4 Environmental Management Systems (EMS)

Environmental management system (EMS) is defined as the part of an overall management system that includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing, and maintaining the environmental policy, with the overall aim of continuous environmental improvement (Curkovic et al., 2005, Lozano and Valles, 2007, Lundberg et al., 2007). Furthermore, both the European Eco-Audit Ordinance named environmental management and audit system or eco management and audit scheme (EMAS) and ISO 14001 described EMS as providing a solid basis for continuously improving the environmental performance of a company (Ljungberg, 2007, U. Tischner et al., 2000).

The relationship between Eco-Design and EMS systems from the fact that the implementations of EMS is intended to promote mainly process innovations towards improved environmental quality in combination with decreased cost, indirectly they may also stimulate product innovations in the field of eco-efficient products and services (Rennings et al., 2006). It is argued if both EMS and Eco-Design are introduced; they can support and complement each other, with synergetic effects. To integrate Eco-Design into EMS means that Eco-Design processes have to be incorporated in the company’s environmental policy and programme and workflows and responsibilities relating to the implementation of Eco-Design need to be built into the environmental management manual (U. Tischner et al., 2000). Lucent Technologies specialised in mobility solutions, has pioneered a product-based environmental management system (PBEMS) by combining Eco-Design and EMS (Donnelly et al., 2006).

2.6 Eco-design Activities

This section covers Eco-Design process definition, principles of Eco-Design, DFX and Eco-Design, how to link industrial ecology to business strategy, integrated management system, and environmental voice of customers and engineering metrics.

2.6.1 Eco-Design process definition

The process of Eco-Design is not essentially different from the conventional product planning process. However, its aim is to integrate environmental product planning processes wherever this is meaningful and possible.

2.6.2 Eco-Design principles

Until now, the emphasis in business has been on minimising the effects of manufacturing processes or operations; the pressures for Eco-Design require additional ‘life cycle’ thinking. The main life cycle stages are (Clark, 2002, Ljungberg, 2007, Tsoulfas and Pappis, 2006, Vezzoli and Sciama, 2006)**:**

- Raw material extraction and transport.
- Primary material processing and transport.
- Product manufacturing and distribution
- Product use
- End-of-life

Some general considerations in Eco-Design in relation to the above stages are as follows:

Materials and components

- Avoiding/minimising materials containing restricted, toxic or hazardous substances, which could have an impact at any stage of the life cycle.
- Maximising the content of recycled material (including in procurement specification) and designing plastic parts so that re-grind and/or recycled material can be used.

- Using material, this lends itself to recycling or re-use.
- Minimising the use of scarce natural resources.
- Minimising the energy content in conversion from raw materials.
- Choosing materials manufactured using environmentally responsible processes (e.g. no ozone-depleting substances (ODS)).
- Choosing metal finishes which have the least environmental impact during manufacture.
- Designing for less production waste (reduces environmental impacts from supply chain as well as in production).
- Avoiding over-design. For example, designing parts for equal lifetimes since failure of a single component often means the whole part or product will be discarded (wastes materials and production energy).
- Maintaining a database of the materials used, including quantities, amounts of non-renewable and/or recycled resources and recovery possibilities (end-customers are increasingly requiring detailed information).
- Maintaining a database of components, detailing any hazardous substances and plans to eliminate them, and action needed to use and dispose of these substances safely.
- Including all staff involved in design decisions.
- Discussing these issues with suppliers.

Production

- Identifying implications of design decisions for major changes in the production process, new plant, planning consents, licence etc and allow sufficient time.
- Identifying potential environmental issues and impacts from the production process, including energy use.
- Reviewing the scope for reducing environmental impacts, including implementing pollution and waste reduction and energy efficiency

improvements (monitoring equipment, low energy equipment, energy-saving practices).

Distribution

- Minimising product size and weight.
- Optimising transport/distribution in relation to fuel use and emissions.
- Eliminating packaging if possible.
- Ensuring where possible that packaging is:

-Minimal.

-Re-usable and/or recyclable.

-Returnable.

-Non-hazardous.

-Marked as recyclable or returnable. (using standard symbols, e.g. as adopted by the European Commission).

Use

- Identifying environmental issues and impacts (for most products, the energy consumed during use is the greatest environmental impact. Some use consumables e.g. tapes. Some, such as washing machines also use water and detergents.)
- Technical issues in design for energy efficiency include:

-Design with a ‘sleep’ mode.

-Selecting the lowest appropriate power devices.

-Influencing suppliers to design more energy efficient components.

-Use low voltage logic.

-Avoiding cooled fans or air conditioning. (Instead maximise the thermal tolerance of the design to make then unnecessary).

-Making the product compatible with other energy efficient devices.

-Designing to avoid the forced purchase of a non energy-efficient accessory.

-Considering recovery of excess heat output. (E.g. if used in an air-conditioned building 1.2-1.6 times the heat output of the device will be used to remove the heat from the building.)

-Ensuring equipment is used efficiently. (Provide ‘user friendly’ controls and instruction manuals.)

-Designing for ease of servicing to replace parts and components.

End-of-life

- Choosing an appropriate design strategy for end-of-life. Options depend on type of company and product; mainly applies to equipment manufacturers/suppliers. Options are:

-Scrap

-Disposal of some or all of the equipment/material to landfill or incineration. No

revenue is generated and costs may be incurred.

-Re-use

-Re-sale: The product is resold with minimal refurbishment, for its original purpose.

-Remanufacture/refurbishment: The product is restored to its original condition for resale.

-Upgrade: The product is modified to give it additional functions.

-Recycling

-Materials and or components are recovered: The product is dismantled manually or mechanically.

Reclaiming energy

- The appropriate decision will depend on whether:

-The product is intrinsically suited to a particular recovery route. (e.g. presence of materials of potential value)

-The favoured recovery route makes good business sense. (i.e. costs in relation to value)

-The infrastructure is likely to be in place to make that sort of recovery possible.

-There is an influence over end-of-life practices. (e.g. with a closed system of product stewardship, as in rented or leased equipment or other take-back provisions, equipment can be recovered from the last user)

- Having identified the optimum or preferred recovery route, identifying the required design attributes. E.g. for resale, the attributes include:

-Easy to access to replace parts.

-Easy to change logo identity.

-Compatibility with first and/or second market technologies and standards.

In addition to the above principles, the motivations for sustainable development in section 2.1.2 and the Eco-Design drivers in section 2.3.4.1 of this work, there are many environmental issues for companies to consider, the main issues are (Arslan, 2007, Balaras et al., 2007, Calvo et al., 2005, Clark, 2002,Davison et al., 2006 ,Ljungberg, 2007, Nagase and Silva, 2007, Zmeureanu and Wu, 2007):

Emissions to air

Gases and smoke from raw materials extraction and processing, product manufacture, transport, distribution and use; the main categories and effects are:

-General emissions, including smoke, nitrogen oxides, hydrocarbons and solvents giving rise to local air pollution and smog, with effects on eco-systems and human health.

-Nitrogen and sulphur oxides giving rise to acid rain and potential harm to eco-systems over a wide area.

-CFCs, HFCs and HCFCs and related halons (used in refrigerants and cleaning agents), which deplete the protective stratospheric ozone layer.

-Greenhouse emissions, especially carbon dioxide from combustion, heavily implicated in global destabilisation.

Discharge to water

-Normal or potential (spill) discharges to natural water systems (seas, lakes, rivers, and groundwater) from raw material extraction/processing, transport, and product manufacture, use, and disposal.

-Discharges to foul sewer (and to treatment works) from product manufacture, use and disposal.

Waste

-Liquid or solid waste generated from raw material extraction/processing, transport, product manufacturing, transport, use and disposal.

-Disposal may be via landfill, incineration, or material may be used or recycled.

-Landfill may give rise to groundwater contamination and methane (greenhouse gas) emissions, while incineration may give rise to air pollution and generate ash-requiring land filling.

-Recycling requires processing which gives rise to potential energy and pollution implications, which must be balanced against resource saving benefits.

-Waste disposal is increasingly costly as well as involving the waste of costly raw materials.

Materials use and management

-Fossil fuels and petroleum based materials are finite, their extraction and processing involves considerable environmental effects and risks, while their combustion generates greenhouse and other gases; there will be growing pressures to use them more efficiently. Similar considerations apply to many minerals.

-Some materials (e.g. timber and paper) are from renewable resources (e.g. forests, soils, etc.); their extraction and use (e.g. in packaging) nevertheless involves many environmental effects and there are growing pressures for more sustainable management of such resources.

In addition to the above, materials management is a very important cornerstone of Eco-Design, and without managing it properly, companies cannot claim to be green, or achieve a significant contribution to the environment. Figure 2.5 presents a network diagram of an example of materials management, and the following are some popular principles of materials management (Thompson, 1999):

-Minimize the amount of material in each part

-Lengthen the service life

-Specify re-cycled materials whenever possible

-Specify energy-efficient materials in manufacture and in service

-Specify materials that pollute minimally during their extraction, manufacture, use, and disposal

-Specify readily available materials that do not deplete declining natural resources

-Specify materials that are unlikely to be affected by new legislation that will constrain their deployment, manufacture, or disposal

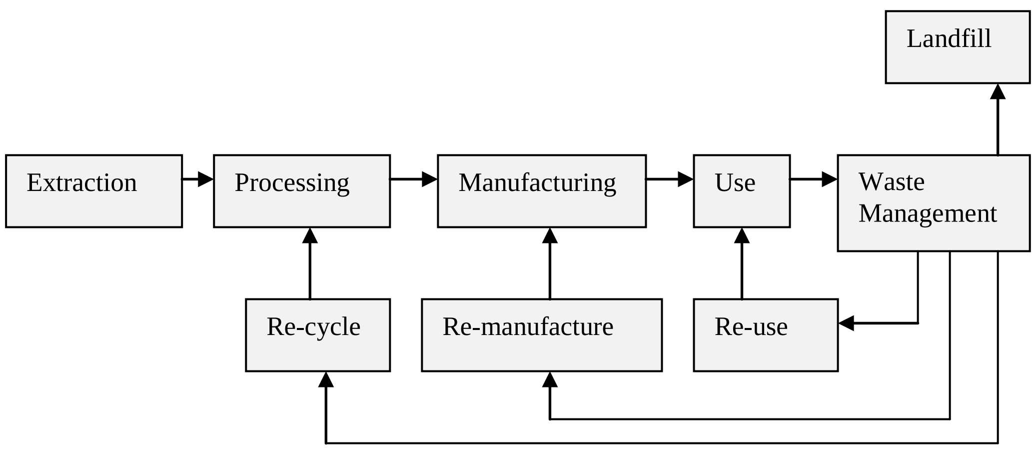


Figure 2-5 Materials management (Thompson, 1999)

Energy use and management

-Most energy is from finite, non-renewable sources and involves the generation of greenhouse and other gases.

-Energy use implications arise at all stages of the life cycle.

-There are growing pressures for energy efficiency, including product energy labelling schemes.

The most important principles for energy management are as follows (Thompson, 1999):

-Minimize energy consumption

-Minimise energy losses

-Choose sustainable fuel sources

Water use

-Water use in processing and manufacturing may be an issue in some areas or times of shortage.

-Consequences of overuse may include depletion of aquifers, general shortages, and harm to wildlife.

-There will be cost implications where water is metered.

Natural environment

-Impacts of the above on fauna, flora and ecosystems may be an issue for some sites and materials

Others

-Other issues and effects may also apply such as noise and nuisance.

-Safety in the workplace.

2.6.3 Design for X (DFX)

DFX was developed in the late 1970s and since the late 1990s, hundreds of papers have been published pertaining to the DFX applications in manufacturing and it is widely used in the development of new products (Kuo et al., 2001, Yang et al., 2007).

DFX emphasizes consideration of all design goals and related constraints in the early design stage (Kuo et al., 2001). The need for DFX tools arises from the fact that designers cannot be expected to be subject experts on every factor that arises during the design process. With DFA (Design for Assembly), for example, issues such as parts orientation; fastening techniques; parts minimization; and feeding techniques are addressed to make one specific stage of the product's life more effective. DFD (Design for Disassembly) is a technique that aids the designer in considering how to do the opposite of DFA at another specific point in the product's life, which is at the end.

2.6.3.1 Design for Assembly (DFA)

DFA analyses product designs to improve assembly ease and reduce assembly time. Often this is accomplished through a reduction in part count. The implementation of DFA techniques has played an important role in reducing costs of manufacturing over the last two decades.

2.6.3.2 Design for Disassembly (DFD)

Disassembly is a vital process if products are to be reused, recycled or even discarded safely. Disassembly is a relatively new and fast growing trend in manufacturing, and will be unavoidable in the future. Several automobile manufacturers have already opened a number of dismantling plants in the United States and Europe, and more are planned in the future (Gupta and Mclean, 1996).

DFD is often carried out using software due to the complexity of the problem. DFD software tools generally calculate potential disassembly pathways, point out the fastest pathway, and reveal obstacles to disassembly that can be "designed out" (Gungor and Gupta, 1999, Hendrickson et al., 1999).

The main differences in design thinking that DFD introduces are the facts that (Gungor and Gupta, 1999):

- Whatever assembles well does not necessarily disassemble well; and
- The order in which a product is disassembled in the real world will have to do with the economic value available from it.

Disassembly is used both in recycling and remanufacturing to increase the recovery rate by allowing selective separation of parts and materials. For example, Kodak's "disposal" cameras snap apart, allowing 87% of the parts (by weigh) to be reused or recycled. Unfortunately, economics costs associated with physical taking apart products to get at valuable components and materials often exceeds the value of the materials. Reducing the time and thus (the cost) of disassembly might reverse this balance. Thus, designing for disassembly (DFD) is important and therefore it has been given special attention. DFD initiatives lead to the correct identification of design specification to minimize the complexity of the structure of the product by minimizing the number of parts, increasing the use of common materials and choosing the fastener and joint types which are easily removable. Thus DFD acts as a driver for recycling and reuse (Gungor and Gupta, 1999, Hendrickson et al., 1999).

Recently, the design for disassemblability/ recyclability becomes more important from the viewpoint of life cycle Assessment or reduced the emission. Therefore, a disassembly support system which can be applied to the design considering reuse / recycle is developed (Wakamastu et al., 2001).

If life span of parts is considered, long-lived parts may be reused as parts but short-lived parts should be recycled and melted as materials.

If the kind of material is considered, some parts can be melted together and others should not. Thus, whether some parts can be kept in-group or must be disassembled individually depends on viewpoints for reuse/recycle. On the other hand, disassembly sequences of products depend on their design. Therefore, disassembly sequences for reuse/ recycle should be evaluated in design process.

However, at the moment end-of life products are hardly reused due to the high disassembling costs, which are often corresponding to the complex product structure of EEE. Within the strategic CARE initiative a consortium of different international companies and research organisations was established in order to build a flexible semi-automatic disassembling cell for extracting valuable components from printed wired boards (PWBs).

Disassembly automation especially for electronic devices is absolutely necessary word-wide in the nearest future because of dramatically increasing amount of electronic scrap (Hoffmann, 2001).

Examples of DFD models

Four-level disassembly analysis methodology

The purpose of this model is to establish a methodology for the evaluation and the optimisation of the disassembly process for material recovery. Designers may be interested in using DFD for different (or combinational) post-life material retirement strategies such as (1) recycling, (2) remanufacturing and (3) re-use. The three post-consumer retirement strategies are defined as material recovery opportunities (MRO). In this model, the focus is on how the design stage may be used to question the feasibility of MRO, rather than the actual details of the individual MRO. The first question of course is related to cost: how much will it cost and what are the trade-offs of recover? Once a decision has been reached to consider recovery, other questions surface, such as (Johnson and Wang, 1995):

- How may the recovery process itself generate the highest possible return of investment?
- Is there a particular disassembly sequence that will maximize the return?
- Is it better to recover only specific components rather than all components?
- What design characteristics facilitate ease of disassembly and how are they to be employed?

All of the above questions may be answered by using a thorough analysis of the disassemble-ability of a product.

The authors have structured such a methodology using a four-level disassembly analysis as shown in Figure 2.6:

Level 1

Feasibility study of MRO: In this level, an initial study is conducted to determine:

1. Percentage of the product (be weight), which is divertable from disposal.
2. Preliminary cost estimates: recovery versus disposal.
3. Other trade-off considerations: learning curve, automation, payback analysis, customer response, trends in legislation, etc.
4. Decision Analysis: both quantitative and qualitative procedures for determining all relevant criteria of the overall feasibility of MRO. Initial goals of MRO may be defined at this stage.

Level 2

Optimal disassembly sequence generation: This level generates a preferred sequence of disassembly, which will maximize the value to be reclaimed in recovery. The disassembly sequence is analysed by considering current design characteristics:

1. Precedence relationship, between components.
2. Characteristics of individual disassembly operations, such as tooling and accessibility and how such characteristics overlap between operations.
3. Clustering of compatible materials.
4. Maximizing the sequence in terms of concurrent disassembly operations and the amount of material recovered.

Level 3

Disassembly optimisation. Using the disassembly sequence generated in level 2, the disassembly is optimised in terms of cost, benefit and degree of disassembly. This level also allows a number of ‘What If’ scenarios to be considered. This analysis results in the following information:

1. Identification of components which suitably adhere to MRO and which do not (i.e. disposal)
2. Identifies if at some point within the disassembly process it becomes uneconomical to continue recovery.
3. Identifies specific component designs, which constrain feasible economic recovery of materials.
4. Identifies components, which will most likely benefit from DFD.

Level 4

DFD guidelines. This level may be considered at any of the above levels depending on the company's commitment and enthusiasm for implementing MRO. The authors are incorporating DFD guidelines into a software program so that designers may assess their present design and make iterative design improvements to enhance the disassembly and economy of material recovery. This is illustrated in Figure 2.6

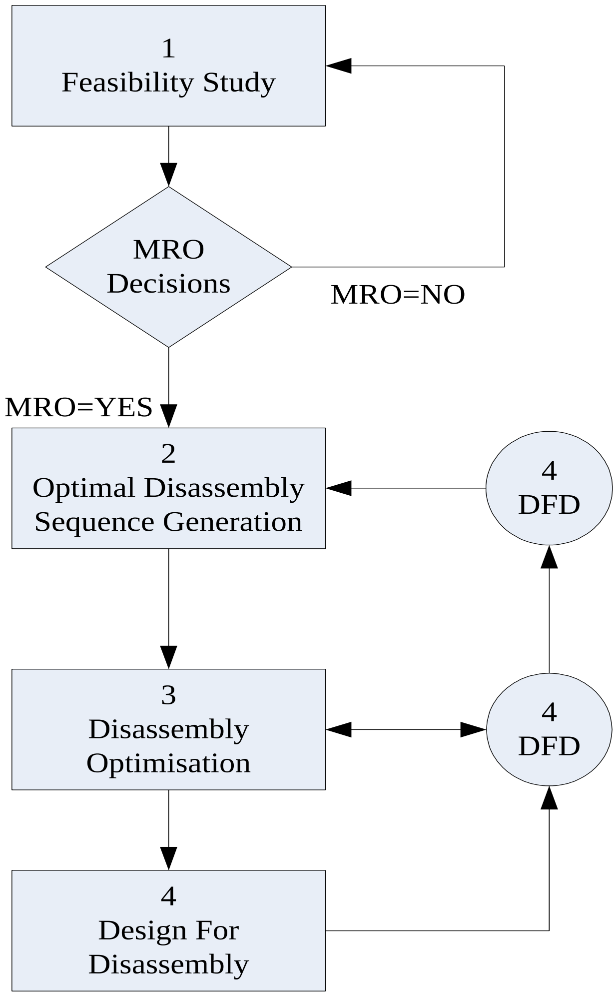


Figure 2-6 Four-level disassembly analysis methodology(Johnson and Wang, 1995).

DFD issues and principles

In order to facilitate disassembly, some of the issues (problems) that need to be addressed during design stages are (Zhang and Kuo, 1997):

- *Ease of separation*. Design for ease of separation, handling, and cleaning of all product components.
- *Fasteners*. New fasteners should be developed, and the existing ones should be improved. Screws, glues and welds should be replaced by other fastening methods. Taking apart a snap-fitted or pop-in, pop-out product is much easier and requires less energy than taking apart a welded product.

- *Modularity design*. The importance of using assemblies in a product's design is to ease dealing with a product after its useful life (i.e., designing with a base part).
- *Material selection*. The variety of material types must be minimized in order to increase the recycle-ability of the product. Highly recyclable materials such as aluminium and thermoplastics should be encouraged, while the use of thermo sets, which cannot be recycled, should be minimized.

Thompson (Thompson, 1999) summarized the principles of DFD as follows:

- Minimize the variety of materials in a product
- Consolidate parts
- Reduce the number of assembly operations
- Specify compatible materials
- Simplify and standardize the fits
- Identify separation points between parts
- Specify water-soluble adhesives
- Incorporate a material identification scheme on parts to simplify identification

2.6.3.3 Design For Recycling (DFR)

In order to reduce the environmental load caused by end-of-life products and improve recycling efficiency, we can adopt two strategies: development of recycling processes, and easier-to-recycle products. Of these, the development of the easier-to recycle products is expected to have the most significant effect (Hiroshige et al., 2001).

Recycling is defined as recovering materials or components of a used product to make them available for new products. Recycling can also think of as practical recycling technology or remanufacturing EOL (end-of-life) products (Kuo, 2006).

So, in order to achieve the goal of easily recycled products, recycling should be considered during the design stage as one of the design priorities.

Recycling is the last of the three Rs – reduce, reuse, recycle-perhaps because:

- If it is possible to *reduce* the need for a product or material, this is the ideal situation.
- If this is not possible, as long as the product or material can be *reused* at the end of its first useful life, at least its life is prolonged.
- If neither of these is possible, the product or material should at least be *recycled*.

The new EU Directive on Waste Electrical and Electronic Equipment (WEEE) specifies minimum recycling requirements for different types of product by July 2006 (Clark, 2002)

DFR arises from the widely accepted need to reduce the amount of waste that goes to landfill and the fact that complex products contain materials that require separating before they can be recycled (McAloone, 2000).

The following are a set of practical arguments for recycling (McAloone, 2000,Zhang and Kuo, 1997):

- Limited raw material resources.
- Growing consumption causing growing volumes of waste and waste-related problems.
- Problems in disposing of products containing hazardous or otherwise problematic waste.
- Ceasing capacity of existing dumping areas and lack of or local opposition to new ones.
- Increased expenses for waste handling and disposal.
- Growing ecological awareness and trends preferring 'eco-products' in the market.
- National and international legislation demanding recycling and recycle-ability.

DFR issues and principles

The following guidelines for DFR generally cover holistic design issues rather than specific ones and include issues such as (McAloone, 2000, Thompson, 1999, Zhang and Kuo, 1997):

- Using recycled material.
- Minimise the number of different materials in a product
- Selecting materials that are compatible with recycling.
- Designing for disassembly (DFD).
- Reducing labelling on plastics (if label adhesive is incompatible).
- Reducing hazardous materials such as in cathode ray tubes or batteries.
- Making hazardous materials easy to access for removal.
- Selecting recyclable packaging.
- Maximisation of profit (benefits – costs) over a product's life span.
- Maximisation of the number of parts reused.
- Minimisation of the amount (weight) of landfill waste.

Consider the following when designing for recycling (clark, 2002):

- Design for manual and mechanical dismantling
    - Some manual dismantling will normally be required to remove the components intact.
    - Mechanical dismantling (shredding) is possible as long as the resulting material streams can be separated efficiently and there are no hazardous materials or components, which could cause contamination.
    - Manual dismantling is normally more costly than mechanical but gives higher yields.
    - The optimum may be determined by a mixture, e.g. manual for high value or hazardous components and large parts, and shredding the reminder.

        - The optimum may be determined by practical trials, economics and regulation; information may usefully be provided to recyclers
    - Design for reverse assembly or brute force
        - If a product is designed for reverse assembly it will be easy to replace failed parts to extend its life or make it suitable for re-use.
        - The cost of separating different types of materials and components may be minimised by grouping non-recyclable or hazardous components, identifying break points to snap off a non-recyclable part, or using small throw-away inserts
- Use fewer material types
    - Reduces production costs through economies of scale.
    - Allows easier assessment of environmental impact.
    - Increases the volume and value of material at end-of life.
- Select compatible polymers
    - Ideally the same polymers should be used throughout a product
    - If this is not possible compatible types should be used: these do not need to separated for recycling since the resulting blend will be a usable alloy e.g. polycarbonate (PC)
    - Screws and fastenings should be made of the same material
- Avoid contamination such as labels and adhesives
    - Unless labels and adhesive are compatible with the moulding polymer they should be avoided.
    - Information can be moulded onto a product using surface finish to increase visibility, or laser printed directly onto the moulding.
    - Painting or electroplating of plastics should be avoided.
    - If label is used it should be of a material compatible with the moulding.
    - Ultrasonic welding, heat staking and spin welding, hot plate or hot gas welding can be used.
- Identify polymers
    - Maximising the value of polymers requires identification of and dating the material
    - This can be done by an in-mould code and /or bar code, displaying the material category as PC and including additives, colour and number of

recycling cycles, as in ISO 1043 on acronyms and ISO 11469 on marking components.

Henstock (Henstock, 1988), reviewed recycling practices for various metals based items, which focuses on steel scrap in automobiles. The study has generated some general principles of design for recycle-ability including the following:

- Simplify mechanical disassembly.
- Avoid self-contaminating combinations of materials.
- Standardize materials used.
- Separate high copper content items from steel items

In order to make products easier to recycle, it is necessary to take the ease of disassembly, processing and final treatment into consideration at the design stage. Therefore, an advanced evaluation method that can evaluate a product’s ease of recycling with minimal prototyping and testing of the product is required at the early design stage.

Wittenburg(Wittenburg, 1992) proposed the concept of recycling paths of components and materials, as envisaged by BMW. It entails a “cascade model” of decreasing values, in which attention is first focused on the disassembled parts suitable for re-use that have the highest value. The Decree on Electronic Wastes and the Decree on Used car forced manufacturers to reclaim waste, to reuse the recyclable fraction, and to dispose of the residue. In the automobile industry, BMW is the leader in design for recycling and disassembly. The Z Model is a two-seat automobile with an all plastics skin that can be removed from the metal chassis in 20 minutes. The doors, bumpers, and front, rear and side panels are made of recyclable thermoplastics produced by GE. The BMW 325 also uses recyclable plastic parts and targets its markets to the environmental conscious customers. Through these efforts, BMW has identified some guidelines that make disassembly and recycling easier.

2.6.3.4 Design for Manufacture (DFM)

DFM is the practice of designing products with manufacturing in mind. Early considerations of manufacturing issues can shorten product development cycle time, minimise overall development cost, and ensure smooth transition into production. Involving manufacturing early in development is not meant to seek their approval on all aspects on all aspects of the design. Instead, when complete prototypes have been built, adequate manufacturing input should be sought on the potential manufacturing challenges for the product to migrate into production. This prevents gross assumptions about the manufacturability of the product, which if proven false, can have cost ramifications on the commercial success of the product. Traditional sequential product development methods do not recognise the impact that design has on the downstream functions such as manufacturing (O'Driscoll, 2002).

Furthermore, to be effective in product design, the procedures of both DFA & DFM are often combined as Design for Manufacture and Assembly (DFMA). The aim of DFMA is to maximise the use of manufacturing processes and minimise the number of components in an assembly of product (Edwards, 2002).

2.6.3.5 Design for Quality (DFQ)

Since inspection and statistical quality control can never fully compensate for poor design, quality must be designed in the product. The objectives of design for quality (DFQ) are (Kuo et al., 2001): (1) design of a product to meet customer requirements, (2) design of a robust product that can counter or minimize the effects of potential variation in manufacture of the product and the product’s environment, and (3) continuously improve product reliability, performance, and the technology to exceed customer expectations and offer superior value.

QFD is a means of ensuring that customer requirements are accurately translated unto relevant technical requirements throughout each stage of the product development process (halog et al., 2002).

2.6.3.6 Design for Serviceability (DFS)

Serviceability analysis commonly occur in later stages of the design process when design changes and either costly or infeasible (Bryan et al., 1992).

In general there are three components of serviceability: Diagnosis, Access, and Disassembly. Serviceability guidelines tend to be qualitative and very industry specific. Consequently few general guidelines exists; however those that are readily apparent are listed below (Brett, 2002):

-Minimise the number of layers of components.

-Make components that are most likely to fail or require servicing to be close to the surface.

-Develop a modular product structure.

-Minimise the number of connections between subassemblies.

-Use standard components where possible.

-Minimise the variety of components and fasteners used.

2.6.3.7 Design for Testability (DFT)

DFT is a name for design techniques that add certain testability features to a microelectronic hardware product design. The premise of the added features is that they make it easier to develop and apply manufacturing tests for the designed hardware. The purpose of manufacturing hardware is to validate that the product hardware contains no defects that could adversely affect the products' correct function (Koenemann, 2006).

Testability should be introduced at the design stage, where it dramatically lowers the cost of test and the time spent at test. Properly managed, testability heightens the assurance of product quality and smoothes production scheduling thus reducing time to market.

2.7 Eco-Design Tools

The Eco-Design tools listed in this section are taken from current Eco-Design literature and practice or developed at eco-concept. Depending on the problem and task these tools can be selected.

Tischner (U. Tischner et al., 2000)divided the Eco-Design into four categories:

1. Analysis of environmental strengths, and weaknesses.
2. Implementation: providing assistance for design, brainstorming and specifying the details of ideas. The tools in this category come under the heading of enhancing creativity and finding ideas.
3. Setting priorities, and selecting the most important potential improvements.
4. Coordination with other important criteria: cost-benefit analysis, economic feasibility studies

In the following sections, the above categories are presented in some detail.

2.7.1 Tools for analysis of environmental strengths and weaknesses

The analysis stage involves the identification, quantification, evaluation, and prioritisation of environmentally harmful issues in relation to a product, a product system, a service or a concept (U. Tischner et al., 2000). In the literature, the most mentioned tools, which are relevant to this section, are as follows:

- Life Cycle Assessment (LCA): Tool to identify and assess the potential environmental impacts associated with a product throughout its complete life cycle.
- MIPS Analysis (MIPS = Material Input Per Service unit): Tool to identify and assess the environmental impacts connected to a product, process, or material throughout its life cycle taking account of energy and materials inputs.
- CED Analysis (Cumulative Energy Demand): Tool to identify and assess a product’s environmental impacts across its life cycle on the basis of its energy input and content.

- MET Matrix (Material, Energy and Toxicity) and Eco-Design Checklist: The purpose of the tool is the systematic check (Eco-Design checklist) and presentation of environmental improvement potential and an assessment of the product using energy, material and toxicity data (MET Matrix).

- Spider Web (Polar Diagrams): The purpose of the tool is the assessment of products against a set of environmental criteria chosen by the user; comparison of different designs/products/solutions; excellent for discussions, overviews, presentations and as education material.

- The Eco-Compass: The Eco-compass was developed by DOW Europe as part of the company's Eco Innovation process. It is used for a holistic description of the product's environmental aspects according to the chosen criteria.

- The LiDS-Wheel: It can be used together with the MET Matrix and Eco-Design Checklist with the help of eight Eco-Design strategies (one for each spoke). It gives an overview of environmental improvement potential to the designer. Data from a roughly analysed reference product is entered in the diagram and according to the eight Eco-Design strategies improvement options for the product shall be identified.

- The Spider-diagram e-concept: The Spider-diagram was developed by eco-concept uses a flexible set of criteria. The definition of the axis will depend on the focus and scope of the planning task as well as on users needs, and it results in a different emphasis for each exercise. The 'Spider-diagram' may also be used in a workshop with the relevant actors in product development.

- Checklists: The purpose of the tool is the assessment of products and design solutions; a guide for the development process; a reminder of the most important environmental aspects; an internal and external communication of environmental aspects.

- ABC Analysis: The ABC Analysis method is used for the assessment of environmental impacts incorporating a number of groups of criteria which lead to three values: ‘A = problematic, action required’, B = medium, to be observed and improved’, ‘C = harmless, no action required’.

- Eco-Design Strategy Wheel (ESW): The ESW as developed by the Delft University of Technology (DUT), distinguishes 33 Eco-Design principles (clustered in 8 Eco-Design strategies), possible ways to improve the environmental profile of a product system taking all the stages of its life cycle into considerations.

- Life Cycle Design Checklist: Life-cycle design checklists are used to assess the design and management throughout the product’s life cycle, including the circulation of materials, energy, money, value, information and knowledge. Therefore, broad-perspective activities for executing production, use, maintenance, reuse and disposal in a manner, which minimises environment impact and the consumption of natural resources.

- Expert rules, Rules of Thumb: The purpose of the tool is to facilitate and enhance communication of experience, provide simple rules for engineers and designers in the field of product development, procurers and others; and useful for educational purposes.

- Quality Function Deployment (QFD): Explained before in this chapter.

- WEEE (Directive on Waste from Electrical and Electronic Equipment)

  The purpose of this directive/tool is to make producers responsible for the costs of the collection and recycling of their products at the end of usable life. This is considered to give producers a financial incentive to reduce waste at source through Eco-Design (Gottberg et al., 2006).

2.7.2 Tools for enhancing creativity and finding ideas

Creativity techniques are important and inspiring tools in the Eco-Design process, especially during the idea generation phase. Tools, which could help are presented as follows:

- Classical brainstorming: Classical brainstorming is the oldest (1963) and most common creativity technique used by companies and organization. The main reasons are that it is inexpensive, stimulates communication and does not require much time.

- Brain-writing: The advantage of this method when compared to brainstorming is that it gives more reserved participants the opportunity to get involved in the process as its more anonymous.

- Bionics: The basic idea of bionics is to copy systems or structures observable in nature and use them for engineering technical solutions. The impetus for the idea need not necessarily comes from a concrete technical problem: it can also be that the principles discovered in nature inspire a search for technical problems, which they can help to solve.

- Progressive Abstraction: An essential feature of progressive abstraction is the repeated question 'what are we actually aiming for?' This repeated challenging of the problem definition has the effect of gradually increasing the problem's level of abstraction. In this way the problem solver is encouraged to look at the problem from different viewpoints and search for solution at a more fundamental level.

- Morphological Box: The term morphology means the study of structures, shapes and forms in the material or mental sphere. In the context of creativity techniques it refers to a systematic orderly manner of thought. The morphological box is a tool for practicing this type of thought. It is a grid in which a problem can be broken into individual parameters (components), which can then be varied. This technique can be used by one person or in groups.

2.7.3 Tools for setting priorities, making decisions, and selecting the most important areas of potential improvements

These tools help in decision-making, selecting solutions and setting ecological criteria for product development alongside the mainstream criteria for produce ability, customer satisfaction, reliability, aesthetic, etc. The aim is to increase the overall product quality together with the product’s environmental performance. Tools, which could help are presented as follows (Tischner et al., 2000):

- Eco-Design Matrix: The purpose of this tool is to compare different alternatives, eliminates unsatisfactory solutions; combines ecological, economic, customer-related and social improvement potential with technical and financial feasibility.
- Checklist for Selecting New Solutions: The purpose of this tool is to help assess a solution on the basis of the minimum and the most important desirable requirements for the solution (ecological, economic, customer-specific and technical aspects); it compares different alternatives and eliminates unsatisfactory ones, identifies gaps in one’s knowledge and additional information that is needed; well suited for discussion processes.
- Eco-Design Portfolio: Compares different alternatives; eliminates unsatisfactory solutions; identifies the best alternatives; combines ecological, economic aspects with technical feasibility.
- Quality profile ‘Pragmatic Differential’: Determines the quality profile of potential solutions, thus permitting solutions to be compared visually; combines ecological, economic, customer-related, social, technical criteria, etc. The user can add his own, or modify existing criteria.
- Dominance Matrix or Paired Comparison: Sets up a ranking of competing criteria, and different potential solutions etc. on the basis of a systematic comparison of each individual criterion with all other criteria or of all solutions.
- House of Environmental Quality (HoEQ): Presents the relationships and influences between different Eco-Design strategies and user demands as well as ecological, economic and internal demands; points out dilemmas; sets priorities; can be used for finding goals and solutions in discussions. It is a main part of the Quality Function Deployment (QFD) tool.

2.7.4 Tools for cost estimation / environmental cost accounting

These tools are particularly important for estimating the environmental costs associated with existing products and the changes in costs resulting from products' improvement. Their purpose is to determine cost effects (reduction or increases) of environmental-related improvements, so that the range of possible solutions can be narrowed down to those that not only reduce the environmental impact of a product but also lower costs. Tools to help achieve this task are presented as follows (Stevels, 2001, U. Tischner et al., 2000)**:**

- Benefit analysis: Benefit analysis is a tool, which requires relatively little time and is well suited to the idea generation and design phases of the Eco-Design process.

- Life Cycle Costing (LCC): LCC includes consideration of impacts of a product beyond the production phase (e.g. restructuring of distribution, packaging, repair costs, energy demand during use, taxes, product liability etc.).

- Full Cost Accounting (FCA): FCA adds a further dimension to LCC by taking account of the effects of a product has on specific stakeholders and the costs this entails for them. Whereas TCA focuses on the producer and LCC on all actors affected by the product lifecycle, FCA widens the horizon to include all externalised costs, which are involved in the product life cycle and at present are borne by the community at large.

- Total Cost Accounting (TCA): TCA was developed in the late 1980s as part of the cleaner production concept. TCA aims at revealing costs that are difficult to pinpoint or are hidden including liability costs e.g. the obligation to clear up after accidents costs of medical care or compensation for damaged property and so on.

- Cost Accounting and Eco-Design: In Eco-Design, environmentally oriented cost accounting should primarily be focused on cost factors, which are capable of being influenced by the Eco-Design process generally and specifically during the different planning phases. This includes, in particular, energy, material; disposal (waste/waste water) and pollution considerations as well as stakeholder-specific environmental costs.

2.8 Eco-Design performance measurement

In order for any organisation to check the progress status of its work in any field, it has to have a process of measuring such progress. The same applies for Eco-Design implementation programme.

The tools listed could be utilised where possible to measure performance. In addition statistical tools such as Statistical Process Control (SPC) could be used to measure and monitor performance.

2.8.1 Motivators for using performance measurement

The motivators for using performance measurements do not significantly differ from the motivators for Eco-Design implementation. The following is a list of these motivators (Stevels, 2001, U. Tischner et al., 2000)**:**

- To promote goods and services
- To improve Eco-Design activities
- To comply with regulations and authority
- To monitor performance
- To communicate performance to interested parties.
- To benchmark against the best in the market
- To benchmark against own historical performance

2.8.2 Eco-Design performance levels

The total Eco-Design process is described as going up a staircase with four steps (Stevels, 2001):

First step (level): Incremental improvements of products

Second step (level): Complete redesign of existing product concepts

Third step (level): Alternative fulfilment of functionality, new concept

Fourth step (level): Functionality designs completely fitting in the sustainable society

2.9 Problem definition

The main points in the outcome of the literature review were the deficiencies of the existing Eco-Design programmes and its related activities. Among other deficiencies, the problems or gaps, which are identified by the author as a result of the literature review, could be classified as follows:

1. The lack in the literature of both comprehensive, generic Eco-Design frameworks and the lack of preparation to implement the WEEE and RoHS.
2. The significant shortages in the literature on how to integrate, Eco-Design programmes in the business's normal operation and strategy. Most of the work in the literature is on how to integrate Eco-Design attributes or environmental aspects into product design to help to apply WEEE and RoHS directives.

As a result, the work in this field is still limited to small number of publications, while most of the work is still concentrated in the field of integrating environmental aspects in product design. Subsequently the overwhelming numbers of Eco-Design frameworks developed are still focusing on the latter, and yet nearly 90% of all eco-technically good products will not be a success on the market for various reasons (Ljungberg, 2007). In addition, a large number of companies have not started Eco-Designing their products and processes and most of the attempts are lacking vigour and momentum. Eco-Design is still being treated as an isolated project or venture stuck in the designer office, and that could be one of the reasons for eco-products not making it to the market.

2.10 Critique on the literature review

The huge increase of waste and dwindling of non-renewable natural resources such as materials and energy is the result of excessive use and according to the European Commission the total amount of waste of electrical and electronic equipments is expected to increase by about 45% between 1995 and 2020. It is argued that the high emission of CO_2 is to blame for the global warming phenomenon, which threatens the life on earth.

The literature review highlighted the need for more and more environmentally friendly products, which causes less impact on the environment in terms of materials and energy. The author presents the main points found and discovered as a result of the literature review as follows:

- Environmental attributes should be dealt with at the design stage and through the whole life cycle of products. As applying WEEE and RoHS directives while designing the products.
- Companies should prepare themselves for more and tighter regulation and legislations. By applying a green product from the beginning.
- Treating the environment as customer is a step on the right path to the journey of sustainable design and this is very essential to apply any legislation as WEEE and RoHS as a customer is the very important part in it.
- The number of green consumers is on the increase and they expect products to serve the purpose with excellent environmental superiority at no extra cost and in some cases they expect to make savings by going green.
- Environmental attributes should be dealt with at the design stage and through the whole life cycle of products.
- A stage has been reached where dealing with environmental issues are becoming a prerequisite to design and manufacture of products.
- The available information and knowledge is rather sketchy and based on individual experiences.
- In the literature, the definition of Eco-Design and the process of Eco-Design are rather entangled, and that leads to many different definitions for the same thing. The definition of Eco-Design should be brief, meaningful, and easy to understand and remember

- Eco-Design information is available, even though it is still in its infancy stages, but the challenge is in how to digest, understand and put the information into an effective framework for implementation.
- Companies could have their own DFXs as innovation is a very important part of Eco-Design. In the literature, the emphasis is on DFD and DFR, but the author believes that all DFXs are important, especially if the company thinking of implement the WEEE and RoHS directives.
- It is essential for companies to measure on a regular basis their Eco-Design efforts in order to make sure that they are achieving progress and if not, to be aware of any problems requiring further work.
- Finally, the literature highlights that companies are approaching the subject of Eco-Design as an isolated project, which, if it fails, could be easily blamed and ditched. This flags a significant gap and problem, which could hinder any Eco-Design project from succeeding and achieving its aim and objectives. The author believes that Eco-Design should be embedded in the company's operation and strategy to help to implement the WEEE and RoHS directives in early stage and not to be dealt with as a separate pilot scheme, which could fail, and forgotten. Thus this gap needs bridging, so Eco-Design becomes the normal and natural way of design.

CHAPTER 3 RESEARCH DESIGN AND METHODOLOGY

3.1 Research methodologies

In the following sections, the research methodologies and their related activities are explained. The research process is defined and different research types or approaches are presented and compared. The most popular data capture approaches are discussed. In addition, different types of sampling are presented.

3.1.1 The research process

The research process is the overall scheme of activities in which scientists' engage in order to produce knowledge; it is the paradigm of scientific inquiry (Frankfort and Nachmias, 1996).

As illustrated in Figure 3.1, the research process consists of seven main stages: problem, hypothesis, research design, measurement, data collection, data analysis, and generalization. Each stage affects theory and is affected by it as well.

Research is a systematic investigation to find answers to a problem. Research in professional social science areas, like research in other subjects, has generally followed the traditional objective scientific method. Since the 1960s, however, a strong move towards a more qualitative, naturalistic and subjective approach has left social science research divided between two competing methods: the scientific tradition, and the traditional phenomenological mode (Burns, 2000).

In the scientific method, quantitative research methods are employed in an attempt to establish general laws or principles.

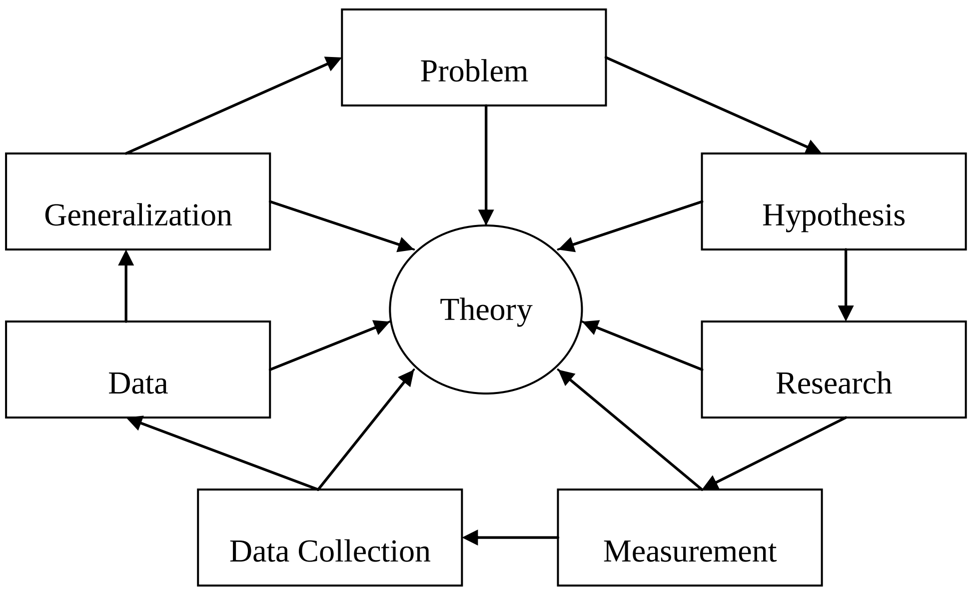


Figure 3-1The Main Stages of the Research Process(Burns, 2000).

Once the research objectives have been determined, the hypotheses explained, and the variables defined, the researcher confronts the problem of constructing a research design that will make it possible to test the hypotheses. A research design is the program that guides the investigator as he or she collects, analyses, and interprets observations.

Any researcher who is about to test a hypothesis faces some fundamental problems that must be solved before the project can be started: Whom shall we study? What shall we observe? When observations will be made? How will the data be collected? The research design is the “blueprint” that enables the investigator to come up with solutions to these problems and guides him or her in the various stages of the research (Frankfort and Nachmias, 1996).

Ideally, research designs should be both internally and externally valid. Internal validity aims to ensure that the research design can sustain the casual conclusions that researcher claim for it. On the other hand, external validity refers to the extent which results from a study can be generalized (De Vaus, 2001).

Robson (Robson, 1993) has developed his own framework for research design as shown in Figure 3.2, which consists of five elements, purpose(s), theory, research questions, methods, sampling strategy.

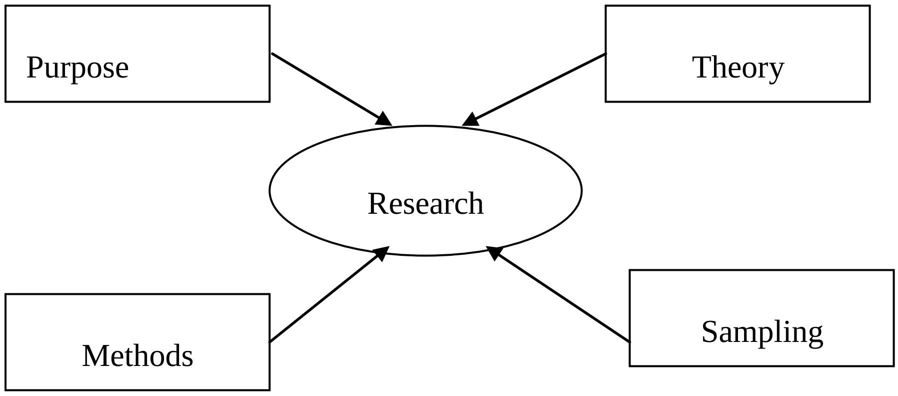


Figure 3-2Framework for Research Design (Robson, 1993)

3.1.2 Classifications of research purposes

When setting out to explore a research question the researcher should have first decided the purpose of their work.

De Vaus (De Vaus, 2001)classifies the research design into two main types namely description (descriptive research) and explanation (explanatory research), and summarizes them into two fundamental research questions:

1. What is going on (descriptive research)?
2. Why is it going on (explanatory research)?

So, descriptive research focuses on *what* questions, and explanatory research focuses on *why* questions.

Robson (Robson, 1993) classified the purposes of carrying out research into 4 different types:

1. Exploratory
2. Descriptive

3. Explanatory
4. Emancipatory

3.1.3 Research approaches

According to (McAloone, 2000), research is divided into two widely recognized types: qualitative and quantitative.

Triangulation is the third research type characterised by employing several research tools within the same research design (Sarantakos, 2005). The following sections would discuss each of the above types in some detail and seek to compare them to allow good understanding of each approach.

3.1.3.1 Quantitative research approach

Quantitative research is classically understood as being the research that requires facts and figures to answer a research question by means of hypotheses. The research purpose is usually of a descriptive or explanatory nature and the research question will contain verbs such as ‘test’, ‘quantify’, or measure (McAloone, 2000).

According to Kothari (Kothari, 1990), the quantitative research approach focuses on questions such as ‘How many?’ and ‘How often?’ which are easily processed in the form of numbers. Survey and experiment are usually used for data collection in quantitative research.

According to Gordon and Langmaid (Gordon and Langmaid, 1988), the advantage of a quantitative method is that it is possible to measure the reactions of a great many people to limited set of questions, thus facilitating comparison and statistical aggregation of the data. Furthermore, quantitative research holds not only the advantage of statistical and numerical measurement, but also the advantages of sub-group sampling or comparisons. Moreover, the quantitative research offers the possibility to repeat the survey in the future and compare results.

3.1.3.2 Qualitative Research Approach

Research deals mainly with the exploration of issues and the generation of theories within new and emerging subject areas. This ‘soft’ approach to research deals often with human issues and seeks not to scientifically prove a hypothesis, but to develop an understanding in the area (McAloone, 2000).

The researcher will often begin with a research question alone, and then allow an initial period of research (a pilot study) to help develop hypotheses (Robson, 1993).

Nevertheless, the extent to which qualitative designs describe the content of the steps, the degree of rigidity of their instructions and the design of the flow of the research process vary considerably, presenting at least two types of qualitative designs: the fixed and the flexible designs (Sarantakos, 2005).

Fixed qualitative designs: The fixed model of qualitative design employs a relatively structured approach resembling the quantitative model.

Two important points must be kept in mind when this research model is considered. First, this model is employed when the researcher has a clear idea about the nature of the research topic and is interested in the way, which people respond to it. Second, it is employed when data analysis is conducted partly or entirely after data collection. This is for instance the case when data are recorded mechanically, and are analysed after collection.

Flexible qualitative designs: More common is the flexible model of qualitative research. The flexible qualitative design has the following feature (Sarantakos, 2005):

- Contains six major steps
- Is constructed before the research commences
- Is presented in a general and non-specific manner, allowing interpretations, leaving space for further decisions to be considered.
- Allows freedom of unlimited movement between the steps of data collection and data analysis in both directions, using new information to fine-tune

concepts, sampling and analysis. Qualitative enquiry does not employ a one-way research process.

- Is not based on objectivity; it follows strictly professional standards; it allows personal preferences of the researcher

3.1.3.3 Comparisons between quantitative and qualitative designs

According to Sarantakos (Sarantakos, 2005), the differences between fixed qualitative and quantitative designs are minimal; they lie in the content of each step and particularly in the nature of the research focus and methods used, not in the structure of the design. The differences between quantitative and flexible designs are more obvious and more significant. Even when the same concepts and elements are used, their content purpose and nature often vary considerably. The basic differences between these two research models are shown in Table 3.1.

Table 3-1 Research designs: a comparison (Sarantakos, 2005)

Procedure	**Quantitative model**	**Qualitative (flexible) model**
Research topic	Selection of research topic Selection of methodology	Selection of research topic Selection of methodology
Methodological construction of topic	Definition: Precise, accurate and specific Employs operationalisation Hypotheses: formulated before the study	Definition: general and loosely structured Employs sensitising concepts Hypotheses: formulated through/after the study
Methods, sampling and projections	Well planned and perspective Sampling: well planned before data collection; is representative Measurement/scales: employs all types Arranging printing of documents Appointing assistants if required	Well planned but not perspective Sampling: well planned, often during data collection; is not representative Measurement/scales: mostly nominal Planning field visits Appointing assistants if required
Data collection	Uses quantitative methods Employs assistants	Uses qualitative methods Usually single handed
Data processing	Mostly quantitative and statistical analysis Inductive generalisation	Mainly qualitative; often collection and analysis occur simultaneously Analytic generalisation
Reporting	Highly integrated findings	Mostly not integrated findings

3.1.3.4 Triangulation methods

According to Sarantakos (Sarantakos, 2005)triangulation refers to the practice of employing several research tools within the same research design. Initially, triangulation was used to reflect what was known as multiple operationalisms or convergent, and since it usually entailed three paths of action, it was named triangulation. This procedure allows the researcher to view a particular point in research from more than one perspective, and hence to enrich knowledge and/or test validity.

Triangulation as a research methodology combines both quantitative and qualitative methods to conduct different levels of inquiry. Triangulation could be used as a strategy for validating results obtained with the individual methods, as well as for enriching and completing knowledge of these methods. The following are the most common types of triangulation (Sarantakos, 2005):

- *Method triangulation*. This combines several methods in the same study. It employs a mixed-method design to investigate different aspects of the same phenomenon.
- *Time triangulation*. This method entails the use of research at different times, for example, surveying students during the first and last week of their first session.
- *Paradigm triangulation*. Here a number of different paradigms (e.g. positivist and interpretive) are employed to study the same phenomenon.
- *Investigator triangulation*. In this form, triangulation combines the expertise of more than one investigator in the same study.
- *Sampling triangulation*. Here two or more samples are employed within the same project.
- *Theory triangulation*. It consists of using more than one kind of approach to generate the categories of analysis.

It goes without saying that these types of triangulation are not mutually exclusive. More than one form can be employed when required (Sarantakos, 2005).

3.1.4 Data capture approaches

There are many types of research method that can be used to investigate a research question. A research method is a statement of the way in which the researcher intends to collect the data necessary to answer the research question. The research method describes: the type of data; the way in which it is to be collected; and the amount of data to be collected (McAloone, 2000).

3.1.4.1 Literature reviews

The literature review is an important starting point for the researcher to explore the state of the art in the subject area they are planning to research. The literature review should discuss the achievements to date of other research, and bring together work from other disciplines, where necessary, identifying the gap in knowledge which the researcher intends to explore. This is an opportunity for researchers to demonstrate their knowledge of the subject area (McAloone, 2000).

3.1.4.2 Case studies

A case study is an empirical enquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used (Yin, 2003).

According to (Sarantakos, 2005), the characteristics or basic criteria of case study research are as follows:

- It is constructed in natural settings.
- It is suitable for pursuing in depth analysis.
- It studies whole units not aspects of units.
- It entails a single case or a few cases only.
- It studies typical cases.
- It perceives respondents as experts, not as sources of data.
- It employs many and diverse methods.
- It employs several sources of information

Case studies are employed in both quantitative and qualitative research, although to a different extent for different reasons. In general, case studies are employed as pre-research, as the main study and as post-research. In quantitative research they are employed as pre-research, that is, as an exploratory study. In qualitative research they appear as main studies, as research enterprises of their own that aim to develop hypotheses or even theories. Case studies investigate social life within the parameters of openness, communicativeness, naturalism and interpretative-ness (Sarantakos, 2005).

3.1.4.3 Surveys

Surveys are the act of collecting information from a defined community of participants (McAloone, 2000).

In general, surveys are method of data collection in which information is gathered through oral or written questioning. Oral questioning is known as interviewing; written questioning is accomplished through questionnaires, which are administered to the respondents by mail or handed to them personally by the researcher in their homes, at work, at school or any other place; they are returned to the research after completion. These are known as self-administered or self-completion questionnaires (Sarantakos, 2005). In the following sections both types of surveys are discussed.

3.1.4.3.1 Surveys: Interviews

Interviews are a way of gathering data from a relatively large number of people within a defined community, lending themselves well to a survey approach to research. The type of data achieved from interviews is generally of standardised form and is the result of concise questioning (McAloone, 2000).

Interviewing has a strong claim to being the most widely used method of research. Whenever we are getting our bearings, whether it is as researcher or a new arrival in a foreign land, the quickest, most instinctive method is to ask a question. It is therefore no surprise that interviewing takes many forms. The normal way of differentiating types of interview is by the degree of structure imposed on its format (Gilbert, 1993).

According to Gilbert (Gilbert, 1993), the three main types of interviews are standardized or structured interview, semi-standardized or semi-structured interview and non-standardized, unstructured or focus interview.

3.1.4.3.2 Surveys: Questionnaires

Questionnaires are diverse; they vary according to the way they are administered as well as according to their nature. This diversity results in the following types of questionnaire, which are explained in the following sections (Sarantakos, 2005):

3.1.4.3.2.1 Standardised questionnaires

The structure of these questionnaires is highly rigid with a high degree of standardisation, allowing no flexibility in answering the questions. The answers are limited to those set in the questionnaire, and no other ideas, propositions or alternative answers are allowed. They are mostly employed in quantitative research (Sarantakos, 2005).

3.1.4.3.2.2 Un-standardised questionnaires

Generally, the structure of these questionnaires is less rigid, and the degree of standardisation fairly low. They are usually small and the questions well defined but open; hence the responses are unstructured, allowing respondents to formulate their answers the way they want. They are predominantly employed in qualitative and feminist research (Sarantakos, 2005).

3.1.4.3.2.3 Semi-standardised questionnaires

These questionnaires can logically be placed between the two other types, combining a moderate degree of structure and standardisation. Their structure may include a combination of pre-structured and pre-standardised questions and of unstructured and un-standardised parts. The extents to which structure and standardisation are balanced vary from case to case with some questionnaires being closer to an un-standardised model. They are employed by both quantitative and qualitative/feminist researchers, although they seem to appeal more to the latter (Sarantakos, 2005).

3.1.4.3.2.4 Open-ended and closed formats

Questions can be divided into two formats, closed and open-ended (Miller and Brewer, 2003):

A closed question presents the respondent with a predetermined selection of responses. Closed questions have an advantage in that they are more straightforward to answer and the responses are faster to code. In contrast, open-ended questions give the respondents the opportunity to give an answer to the question in their own words.

However, coding open-ended responses and comparisons between respondents are more difficult.

3.1.4.3.2.5 Response sets or scales

The following are possible ways to form response sets in the context of questionnaires; while some are more common than others, all have been and are currently being used by social researchers (Sarantakos, 2005):

Numerical responses

This response category includes a continuum, with two opposite adjectives such as very satisfactory and very unsatisfactory at each end and a range of numbers in between, one of which must be circled or otherwise marked by the respondents as shown below.

Very satisfactory 5 4 3 2 1 Very unsatisfactory

Verbal scales

In many cases the expected response to a question is formulated in words. The respondent in such cases is expected to tick one of the words in the space provided for the purpose as shown below.

Very high […]

High […]

Moderate […]

Low […]

Very low […]

Scales of increasing strength

Some researchers opt for response categories indicated simply by a descriptor, and are followed by a set of numbers ranging from low to high, from which the respondent is expected to choose such as number 1 standing for very low and number 10 standing for very high as shown in the following example.

Health 1 2 3 4 5 6 7 8 9 10

Graphic responses

The use of graphic responses is not new in social research. In its simplest form, a response contains a continuum whose extremes are defined by two opposite descriptors such as fair and unfair connected by dots or a line.

Fair ………………………………………………………………. Unfair

Graphic-numerical responses

Social investigators quite often use a combination of graphic symbols and numerals. The direction of choice and evaluation is based on the selected position of the tick, which is not defined in words as shown below.

[…] +3

[…] +2

[…] +1

[…] -1

[…] -2

[…] -3

Thermometer scales

In these scales, the responses are set in the form of a thermometer, presenting a continuum that displays the reading range of a thermometer, the extremes of which are described by opposite adjectives, for example ‘Very high’, ‘Very low’. The divisions given on the thermometer are used to reflect the respondent’s level of response.

Face scales

Another graphic scale employed to record answers to closed (pre-coded) questions in a simple manner is the use of faces. Here usually five to seven faces (or sets of faces) of equal size and structure are ordered on a line. The faces are identical, except for the shape of the mouth, which at one end is shaped in a U-form giving the impression of happiness, and progressively changes through a neutral position (straight line) to an inverted U at the other end describing unhappiness.

The respondents are asked to indicate their feelings to the question by marking the appropriate face.

Likert-scale questions

Likert scales are widely used, particularly as a means for studying attitudes. The response categories range between two extreme positions divided into five points corresponding to a verbal-numerical scale, for example ‘Very positive’ down to ‘Very negative’ as shown below.

Very positive	5
Positive	4
Neutral	3
Negative	2
Very negative	1

Ranking scales

Unlike many scales in which respondents are asked to tick one response only, ranking scales require that all responses be answered, for example by ranking them from highest to the lowest. In such cases there are as many ranks as there are items.

Ladder scales

In a response set that employs a ladder scale, the responses are given on a ladder presenting a continuum of five or more steps, whose extremes are defined by two opposite adjectives (e.g. ‘high’, ‘low’, or ‘strong’, ‘weak’). The question could be, for example, ‘where do you stand on the social ladder?’ advising the respondents to place an X on the point of their choice.

Constant-sum scales

These scales ask respondents to score two or more objects or concepts so that they together add up to a given number (e.g. 100). This measure is most suitable to ascertain, for instance, the psychological distance between stimuli.

Semantic differential scales

These scales are employed to evaluate social units such as teachers, parents, friends or politicians. They contain a set of opposites (up to 70) relating to three major dimensions; these are (a) general impression, (b) power or potency and (c) activity. The space between the opposites is graded from 0 expressing the lowest evaluation (e.g. very bad, very weak, and very low) to 6, representing the highest evaluation (e.g. very good, very strong, and very high).

3.1.4.3.2.6 Steps in questionnaire construction

Questionnaires are constructed in a very focused and systematic manner. The process of construction goes through a number of interrelated steps, and offers a basis for the research stage to follow. The following are the most common steps in questionnaire construction (Sarantakos, 2005):

Step 1: Preparation

The researcher first decides what the most suitable type of questionnaire is, and determines the way it will be administered. There should also be a search for relevant questionnaires that might already have been developed by other investigators. If suitable questionnaires are found, they can either be adopted for the study or used as guides in preparing the new one. If the search is unsuccessful, the researcher will proceed with construction of a new questionnaire.

Step 2: Construction the first draft

The investigator formulates a number of questions, usually a few more than required, including questions of substance (directly related to aspects of the research topic), questions of method (those testing reliability and wording), and secondary as well as tertiary questions.

Step 3: Self-critique

The questions are tested for relevance, symmetry, clarity and simplicity, among other criteria, as well as for compliance with the basic rules of questionnaire construction presented above.

Step 4: External scrutiny

The first draft is then given to experts for scrutiny and suggestions. It is anticipated that some questions might be changed or eliminated, while new questions might be suggested.

Step 5: Re-examination and revision

The critique offered by the experts and group leaders will be considered and eventual changes implemented. If the revision is not significant, the investigator proceeds to the next step. If the revision is substantial, the questionnaire is presented again to experts and later re-examined and revised until it is considered satisfactory. The investigator then proceeds to the next step

Step 6: Pre-test or pilot study

In most cases a pilot study or a pre-test is undertaken to check the suitability of the questionnaire as a whole (pilot study) or of some aspects of it (pre-test). A small sample is selected for this purpose, and the respondents are requested to respond to all or part of the questionnaire; the results are then analysed and interpreted.

Step 7: Revision

The pre-test and pilot studies usually result in some minor or major changes. If the changes are relatively insignificant, the investigators will proceed to step 8. If the changes are substantial they will return to step 4.

Step 8: Second pre-test

The revised questionnaire may then be subjected to a second test, mainly with regard to the revised questions. This depends on the extent of revision and the complexity of the issue in question. Usually one pre-test is sufficient. The response is considered and adjustments and revisions follow.

Step 9: Formulation of the final draft

In this final step, apart from implementing the suggestions derived from the pre-tests, the investigator concentrates on editorial work: checking for spelling mistakes, legibility, instructions, layout, space for responses, pre-coding, scaling issues and the general presentation of the questionnaire. This copy will finally be sent to the printer.

3.1.4.3.2.7 Strengths and weaknesses of questionnaires

Questionnaires as methods of data collection have strengths and weaknesses, and hence advantages and limitations, that the researcher must be aware of. A list of both is given below (Miller and Brewer, 2003, Sarantakos, 2005):

Strengths

- Questionnaires are less expensive than other methods; in the words of Stelitz (Miller and Brewer, 2003), ‘questionnaires can be sent through the mail; interviewers cannot’.
- They produce quick results.
- They can be completed at the respondent’s convenience.
- They offer a considered and objective view of the issue, since respondents can consult their files and since many subjects prefer to write rather than talk about certain issues.

- They are stable, consistent and uniform measure, free of variations.
- The use if questionnaires allow a wider coverage, since researchers can approach respondents more easily than other methods.
- They are not affected by problems of ‘non-contacts’ (i.e. of respondents who are not available at the time of the study; a problem common in interviewing).
- They offer less opportunity errors caused by the presence or attitude of the interviewer.

Weaknesses

- Questionnaires do not allow probing, prompting and clarification of questions.
- They do not provide opportunities for motivating the respondent to participate in the survey or to answer the questions.
- The identity of the respondent and the conditions under which the questionnaire is answered are not known. Researchers are not sure whether the right person has answered the questions.
- It is not possible to check whether the question order-where required-was followed.
- Questionnaires do not provide an opportunity to collect additional information (e.g. through observation) while they are being completed.
- Due to lack of supervision, partial response is quite possible.

3.1.4.4 Focus group

Focus group research can be best being described as a loosely constructed discussion with a group of people brought together for the purpose of the study, guided by the researcher and addressed as a group. The focus group method appears in two forms, the unstructured or semi-structured form and the structured form, which are employed by qualitative and quantitative researchers respectively. Its popularity is reported to be steadily increasing (Sarantakos, 2005).

3.1.5 Sampling

Researchers collect data in order to test hypotheses and to provide empirical support for explanation and predictions. Once investigators have constructed their measuring instruments in order to collect sufficient data pertinent to the research problem, the subsequent explanations and predictions must be capable of being generalized to be of scientific value (Frankfort and Nachmias, 1996).

3.1.5.1 Why sample?

We could not carry out everyday life and business if we did not employ sampling in our decisions. The food purchaser examines the fruit on display and, using this as a sample, decides whether to buy or not. Many of our decisions are based on sampling, possibly inadequate sampling in some cases (Burns, 2000). Furthermore, Sarantakos (Sarantakos, 2005) has listed the most common reasons in favour of sampling as follows:

- *Necessity*. In many cases a complete coverage of the population is not possible.
- *Effectiveness*. Complete coverage may not offer substantial advantage over a sample survey. On the contrary, it is argued that sampling provides a better option since it addresses the survey population in a short period of time and produces comparable and equally valid results.
- *Economy of time*. Studies based on samples take less time and produce quick answers.
- *Economy of labour*. Sampling is less demanding in terms of labour requirements, since it covers only a small portion of the target population.
- *Overall economy*. Sampling is also thought to be more economical, since it involves fewer people and requires less printed material, fewer general costs (travelling, accommodation etc.) and of course fewer experts.
- *More detailed information*. Samples are thought to offer more detailed information and a high degree of accuracy because they deal with relatively small numbers of units.

3.1.5.2 Types of sampling

A sample design may involve a mixture of both probability and non-probability (purposive) sampling. The researcher could use purposive sampling to represent the range of types of groups, which are expected to influence the results. However, within each group, probability sampling should be used (Gilbert, 2001).

Sampling procedures vary considerably. Samples may be constructed through self-selection (respondents decide to take part in a study, for example, in response to media call for volunteers) or, as is most common, through the researcher (Sarantakos, 2005).

Criteria for probability and non-probability samples: The main criteria and differences between probability and non-probability samples are listed in Table 3.2 (Sarantakos, 2005).

Table 3-2 Criteria for probability and non-probability samples (Sarantakos, 2005).

Probability sampling	Non-probability sampling
-Employs probability theory -Is relatively large -Size is statistically determined -Size is fixed -Sample is chosen before the research -Controls researcher bias -Involves complex procedures -Has fixed parameters -Involves high cost -Planning is time consuming -Is designed to be representative -Planning is laborious -Treats respondents as units -Facilitates inductive generalisation -Is employed in quantitative research	-Does not employ probability theory -Is small, often covering a few typical cases -Size is not determined statistically -Size is flexible, but can also be fixed -Sample is chosen before and during the research -Does not control researcher bias -Involves simple procedures -Has flexible parameters -Involves relatively low costs -Planning is not time consuming -Representative-ness is limited -Planning is relatively easy -Treats respondents as people -Facilitates analytical generalisation -Is mostly for qualitative research

Probability (random) sampling: Probability sampling is the procedure in which the choice of respondents is guided by the probability principle, according to which every unit of the target population has an equal, calculable and non-zero probability of being included in the sample (Sarantakos, 2005). There are four common designs of probability samples. These methods are discussed briefly below:

- Simple random sampling:

  This type of sampling means that each member of the population should have an equal chance to being chosen and selected as a subject. Simple random sampling has the advantages of simple selection, which comes only after a listing of the whole population before the sampling procedure begins. However, a major disadvantage of the sampling is that it is usually impractical to target all the population (Fink and Kosecoff, 1998).

- Systematic sampling:

  This involves choosing a starting point in the sampling frame at random, and then choosing every n-th person. Thus, if a sample of fifty is required from a population of 2,000, then every fortieth person is chosen. There would have to be a random selection of a number between one and forty to start the selection (Robson, 1993).

- Stratified random sampling:

  Stratification involves dividing the population into separate strata on a characteristics assumed to be closely associated with the variables under study. A separate probability sample is selected from within each stratum. Building stratification into a sample design is recommended because it increases precision for very little additional cost. Stratification ensures that the sample is representative of the characteristic(s) used from the strata (Gilbert, 2001).

- Cluster sampling:

  The fourth type of probability sampling used by social scientists is cluster sampling. It is frequently used in large-scale studies because it is the least expensive sample design. Cluster sampling involves first selecting larger groupings, called clusters, and then selecting the sampling units from the clusters. The clusters are selected by a simple random sample or a stratified sample. Depending on the research problem, researchers can include all the sampling units in these clusters in the sample or make a selection from within the clusters using simple or stratified sampling procedures (Frankfort and Nachmias, 1996).

Non-probability sampling: As the name indicates, non-probability sampling procedures do not employ the rules of probability theory, do not ensure representative-ness, and are mostly used in exploratory research and qualitative analysis. Some of these techniques can, with some adjustment, be converted into probability methods. Accidental sampling, purposive sampling, quota sampling and snowball sampling are examples of non-probability sampling techniques; they are presented below (Sarantakos, 2005):

- Accidental sampling:

  This type of sampling means using subjects who are available to you. This type of sampling can happen as a result of "hanging out" with people you are interested to study. You can hang out on a street corner, at your library, or in a music store to find your subjects (Wysocki, 2004). There are several other names for this type of sampling, including convenience sampling, chunk sampling, gap sampling and haphazard sampling (Sarantakos, 2005).

- Purposive sampling:

  A purposive sample is one in which each sample element is selected for a specific purpose. If you were interested in studying women who are HIV infected to find out about their quality of life, it would be difficult to have a random sample. Therefore, you need to find a group of women who have HIV, and then those women become your sample (Wysocki, 2004). So, the choice of respondents is guided by the judgement of the investigator. For this reason it is known as judgemental sampling (Sarantakos, 2005).

- Quota sampling:

  This type of sampling divides the population into subgroups of quotas such as those of participants' age, sector, region and status. Based on the percentage of the population in each quota, subjects are selected so that the sample matches the population proportion exactly. The main goal of this type of sampling is to ensure that the subgroups in a population are well represented in the sample to the extent the researcher desires (Zikmund, 2002).

- Snowball sampling:

  In this approach, the researcher chooses a few respondents, using accidental sampling or any other method, and asks them to recommend other people who meet the criteria of the research and who might be willing to participate in the project. This process is continued with the new respondents until saturation – that is, until no more substantial information can be acquired through additional respondents – or until no more respondents are available (Sarantakos, 2005). According to Fink and Kosecoff (Fink and Kosecoff, 1998), this type of sampling has great value, especially when researcher has little idea about the size or the extent of the population, or simply has no record of the population size.

3.2 Rationale for research design and methodology selected

The main goal of this research methodology is to achieve the aim and objectives and answers the research's questions of this study. Thus, the research methodology shown in Figure 3.3 is structured in a way that provides the author with a clear roadmap showing different phases of the study and how each phase could be executed successfully. The structure of the research methodology was dictated by the requirements of this research; these requirements were manifested in the research questions to be answered. The answers of these questions will achieve the aim and objectives of this study. The main research questions are as follows:

1. What is the general status of Eco-Design and WEEE directive among the businesses in the investigated sample, and what are the weaknesses and strengths in Eco-Design programmes among businesses in the investigated sample?

2. Are the existing Eco-Design models designed to integrate Eco-Design into the business's normal operation and strategy taking into account the WEEE and RoHS directive?
3. Can an Eco-Design model or fame work be developed, which could accommodate both deploying Eco-Design activities and WEEE directive in order to produce environmentally friendly products and integrate Eco-Design into the normal business operation and strategy in order to guarantee success and continuity?
4. Can the developed framework support an Eco-Design and WEEE directive continuous improvement programme?

Taking into account the above research questions and the review of various possible approaches to research and related topics as shown earlier in this Chapter, a series of research type or approaches, data collection and analysis techniques were chosen. A triangulation approach was employed in this research as deemed to be appropriate, where different types of research were utilised in order to achieve reliable results and conclusions and collect information and data. In the following phases, both qualitative and quantitative research approaches were used. The rationale behind the choices made in this study is presented along with an explanation of each phase of the research. The research was conveniently divided into 5 phases as follows:

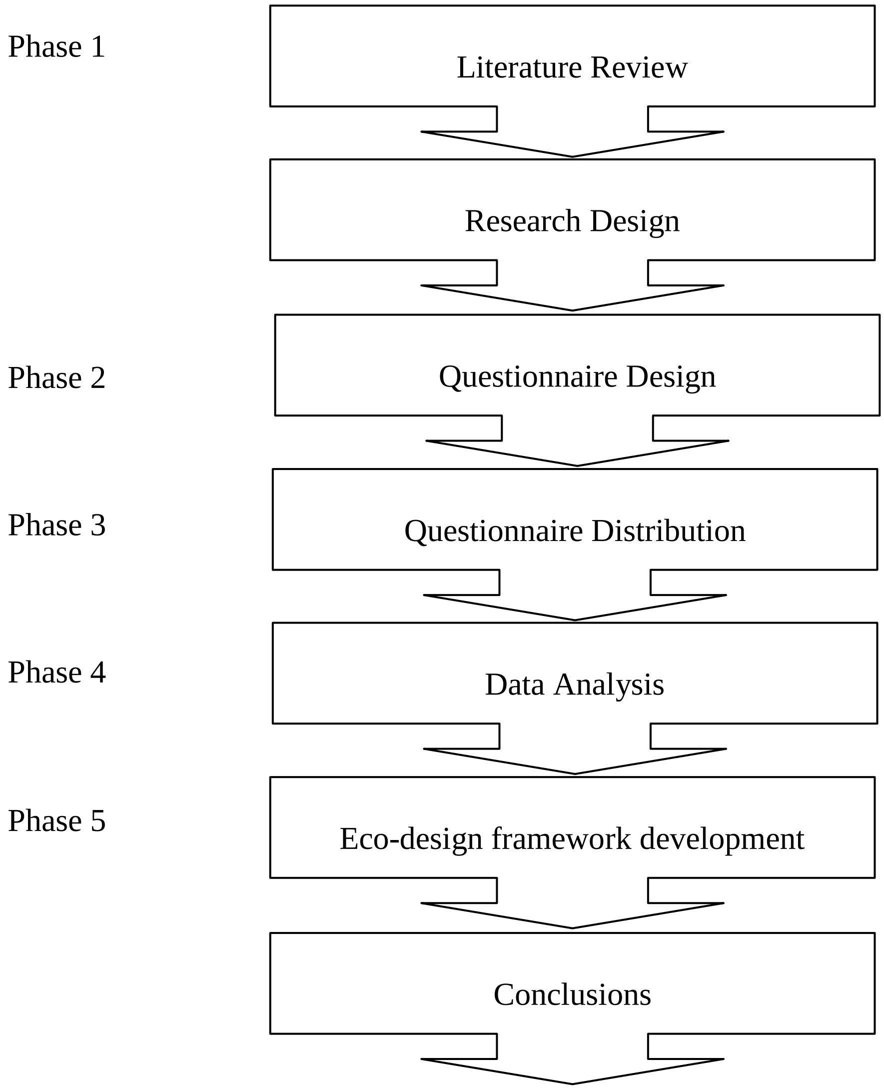


Figure 3-3Research method adopted for the research study

Phase 1

This phase is the foundation of this study, as it is important to review the literature on Eco-Design and related activities in order to identify the present status of Eco-Design in the literature. This will lead to good understanding of the subject and consequently identify gaps and opportunities for further work and research, and this is exactly what happened in this study. As a result of the literature review the aim of this research was established which is *'to provide businesses with a framework, which would help in designing and producing environmentally friendly products by implementing and integrating the Eco-Design activities and WEEE directive into the business's operation and strategy'*.

Having decided and chosen the research purpose, the next step is to select the nature of the research approach or type. It is the objective of the research to investigate the status of Eco-Design activities among a reasonable number of selected samples of businesses referred to in this work as the investigated sample. Therefore, a quantitative research approach is chosen due to its advantage of allowing the measuring of the reactions of a great many people to limited set of questions, thus facilitating comparison and statistical aggregation of the data. In turn, this gives a broad, and generalised set of findings presented succinctly and parsimoniously.

Having decided on the research type, the following part is to select the research method. Due to the considerable size of the Eco-Design activities to be investigated, the size of the investigated sample, and time limitations of this study, a standardised questionnaire survey was chosen. The nature and the structure of this type of questionnaire fit nicely with the objective of this survey. It allows asking questions in a highly rigid format coupled with a high degree of standardisation, thus facilitating reliable and fairly straightforward data collection and analysis among a large number of respondents. The following phase of the research methodology is dictated to the questionnaire development.

Phase 2

All stages of questionnaire developments as shown in this Chapter studied and followed.

Phase 3

A choice was made and justified earlier on in phase 1 to use questionnaire survey in order to explore the subject of Eco-Design, WEEE, related issues and activities. The questionnaire pack included two documents, which includes a covering letter highlighting the main aim and objectives of the research and the actual questionnaire.

A sample of 200 companies from the UK was identified. The sample consists only of companies involved in design and/or manufacturing and has had interest in environmental issues.

Then, the questionnaires were sent by post. 22 questionnaires were returned. 20 were used in the analysis, as the rest were incomplete.

Phase 4

This phase of the research entailed data analysis. Data from 20 returned questionnaires were collected and analysed using SPSS 11 software and the Eco-Design related activities and issues were tested. The data analysis technique employed allowed further insight into the actions of companies. The status of Eco-Design, WEEE, related activities and issues among the investigated sample were analysed and subsequently important findings and conclusions were drawn out. These findings and conclusions influenced the structure, contents and the implementation plan of the developed Eco-Design framework.

Phase 5

In this phase the process of designing an Eco-Design framework, to fulfil the main aim and objectives took place, and based on the conclusions of studying other frameworks coupled with focusing on the main aim of the framework, the PDCA (Plan-Do-Check-Act) improvement cycle was chosen.

3.3 Research population and sampling techniques selected

In this section, the research population to be targeted and the associated sampling techniques together with an explanation of the rationale behind making these choices are presented.

3.3.1 Rationale for Research population selected

In this study the research population within the United Kingdom is rather huge as it involves all companies involved in design and/or manufacturing of products. However, the purpose of the survey is to investigate the status of Eco-Design, WEEE, related activities and issues among environmentally aware companies. The rationale behind that is twofold. The first fold is the actual research nature of Eco-Design activities, which dictates approaching companies who have at least some knowledge of the subject and doing work in this field. Furthermore, the reliability and accuracy of answers could be more guaranteed if respondents who have knowledge about the subject answered the questionnaires. The second fold is that the companies who are involved in WEEE Directive and any of the Eco-Design aspects would be more inclined to answer the questionnaire due to their ongoing interest and knowledge of the researched subject than companies who are not involved at all, thus more replies could be generated.

3.3.2 Rationale for Sampling technique selected

A purposive sample deemed to be appropriate for this survey based on the explanation provided in the above section. So, this is any company who is involved in design and/or manufacturing of products and must have reasonable knowledge of Eco-Design and/or related activities. During the selection of companies to be targeted by this survey, the author made sure that a balanced mixture of different company types and sizes was selected for this sample. It took a considerable time and effort in order to compile and verify the suitability of the sample.

3.4 Questionnaire design

In order to learn from other developed development experiences, research was carried out in order to identify already developed questionnaires in the field of Eco-Design. However, having carried out a comprehensive and detailed literature review, the author did not come across a detailed or comprehensive questionnaire survey about Eco-Design. Instead, the author came across a few and not comprehensive or detailed questionnaires related to the subject during the search of World Wide Web.

In the following sections, the steps of this study questionnaire's development process, administration of the survey and critique on the response rate are presented

3.4.1 Questionnaire design process

The following are the steps used in the questionnaire's development process.

3.4.1.1 Step 1: Preparation

In this step, the questionnaire type was decided as a standardised questionnaire survey. On the whole, the questionnaire would be administered via a postal survey of the chosen sample of companies. The rationale behind this was the large number of the companies to be approached and their geographical locations as they are situated in different parts of the United Kingdom. A postal survey would allow contacting a large number of companies at the same time regardless of their locations.

As stated above, the author benefited from questionnaires from other fields in terms of guidance, structure and contents. However, due to the lack of Eco-Design and WEEE comprehensive questionnaires in the literature, the author had to proceed with the construction of a new questionnaire but benefiting from other questionnaires.

3.4.1.2 Step 2: Construction the first draft

In the literature review part of this study, the Eco-Design activities and related issues were identified and grouped. Then in this step, these activities are translated into questions (variables) format. The questionnaire was divided into different parts with questions about respondents and companies' profiles as it is important to know what sort of person and company is responding to the survey, followed by questions about Eco-Design, WEEE directive, related issues and activities as follows:

- Motivators for Eco-Design
- WEEE and RoHS directives
- Golden rules for eco-product development
- Eco-Design information sources
- Eco-Design levels
- Eco-Design activities
- Eco-Design principles for implementation
- Management of natural resources (materials and energy)
- Environmental voice of customers and engineering metrics
- Tools for Eco-Design
- Eco-Design considerations [design for X family (DFX)]
- Eco-Design performance measures and indicators

- Eco-Design product scoring
- Management system
- Environmental legislation issues
- Linking industrial ecology to business strategy

Each of the above parts includes a set of questions investigating it in terms of strengths and weaknesses. The overwhelming majority of questions offered 6 different answers, requiring only one answer to be filled out. It was possible to comment by adding extra questions to each topic. In addition the researcher asked the same question in more than one part and sometimes in different ways or wordings in order test the reliability of given answers. Thus, at the end of this step a first draft of the questionnaire was completed.

3.4.1.3 Step 3: Self-critique

Having completed the first draft, a complete review of the questionnaire structure and contents was carried out. The objective of this step was to provide the research with a fresh and critical look at the questionnaire in order to test the relevancy of each section in terms of questions asked, their clarity and simplicity. As a result of this step the author had to rewrite some of the questions in order to make them more clear and precise, some questions had to be deleted, and others to change. In addition few more questions were added to the questionnaire. At the end of this part a 1st revised draft of the questionnaire was completed.

3.4.1.4 Step 4: External scrutiny

The objective of this stage was for another party beside the author to examine the questionnaire and offer an opinion and suggestion for improvement. Having reviewed the questionnaire, the author had one to one discussions with them. This step resulted in a few changes to the contents in terms of formulating some questions, deleting others, and an improvement of the questionnaire's format was suggested.

3.4.1.5 Step 5: Re-examination and revision

In this stage the author revised and re-examined the suggestions from the previous step and implemented them. It improved the questionnaire especially the cosmetic part of it as improving the format of the questionnaire made it more marketable. However, on the whole the questionnaire was validated to be satisfactory, clear and to serve its purpose.

3.4.1.6 Step 6: Pre-test or pilot study

In order to test and check the suitability of the newly revised version of the questionnaire, a pilot study was undertaken. Copies of the questionnaire was handed in person and sent by post to people from both industry and academia who were asked to fully answer the questionnaire. 5 completed questionnaires were received, and the results were analysed and interpreted using SPSS software available at the university. As a result of this step the questionnaire was subjected to minor changes whereby a few questions were deleted due to unnecessary repetitiveness.

3.4.1.7 Step 7: Final Revision

As a result of the above step, the author had to delete a few questions, and an up-to-date revised questionnaire was completed.

3.4.2 Questionnaire Administration

The questionnaires were sent to the selected sample with a covering letter from the researcher. The covering letter explained the main aim and objectives in this research, and invited companies to participate by answering the enclosed questionnaire. As an incentive, the covering letter offered the opportunity to any interested company to receive information about the main results and findings of the research. The study involved sending one questionnaire to each company. The questionnaire was sent to the managing director of the company and asked if he or she could answer it or alternatively forward to the relevant person.

3.5 Discussions on the research methodology

The main characteristics of this research approach and related activities are as follows:

- The research approach is to be of both an exploratory and descriptive in nature.
- An intensive literature review exploring and understanding the subject of Eco-Design, WEEE directive and its related activities and issues to be carried out.
- Triangulation would play a significant part in this research.
- The Eco-Design related activities, WEEE directive and issues would be tested by means of an industry wide questionnaire survey among environmentally aware manufacturing companies.
- The questionnaire survey is to be quantitative.
- The Eco-Design related activities and issues would be tested by means of an industry wide questionnaire survey among environmentally aware manufacturing companies.
- A Purposive sampling was employed at this stage.
- The pilot stage of the questionnaire survey will act as verification of both Eco-Design related activities and issues and structure, and would involve both qualitative and quantitative methods.
- The data collected from the industry wide survey will be analysed quantitatively using a software package entitled SPSS11, which is readily available at the University of Bradford.
- The results, findings and conclusions of the data analysis would be used in designing and implementing the proposed Eco-Design framework to take in to account the WEEE and RoHS directives.

CHAPTER 4 DATA ANALYSIS

Data Analysis involves both data preparation and descriptive statistical analysis. Data preparation includes, editing, coding for each question, and then entering into SPSS version (14), a total of 20 valid and usable returned questionnaires were used in the analysis. The researcher carried out the data entry from the questionnaires, and an intensive one by one data check was done for each question.

This process was both time consuming and labour intensive, as a total of more than (3960) entries were checked.

Having entered the data correctly, descriptive statistical analysis was applied in order to summarize and describe the data. The initial phase of this analysis is deemed important, in order to have feeling of the data.

The Analysis of the data is presented in the following sections using Tables.

4.1 Description of the sample

In this section, a general description of the respondent's job title and focus is presented, in addition to the type of companies respond to this survey, the companies' size and whether are member of group of companies or not, and what is the type of their products.

4.1.1 Company size

Table 4.1 shows that this survey included companies from small to large in terms of the number of employees. The overwhelming majority of responses came from medium and large companies.

So, one of the conclusions we could draw from this result that large company are more into eco-design, WEEE and RoHS than smaller ones.

Table 4-1 No of employees

	Frequency	Percent	Valid Percent	Cumulative Percent
Less than 50	2	10.0	10.0	10.0
101 to 200	5	25.0	25.0	35.0
201 to 500	7	35.0	35.0	70.0
More than 500	6	30.0	30.0	100.0
Total	20	100.0	100.0	

4.1.2 Companies membership of group of companies

Table 4.2 shows that 100% of companies responded were part of group of companies, and at the same time nearly 55% of them are part of non-UK based group.

The above figures could lead us to think that companies, which are part of group, are more active in eco-design than independent companies. On the other hand nearly 45% respondents were based in UK, and that would lead us to think that UK independent companies are coming along and paying more attention to the subject of eco-design and WEEE and RoHS.

Table 4-2 Part or not part of group

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	20	100.0	100.0	100.0

Table 4-3 Partners nationality EU other than UK

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	11	55.0	55.0	55.0
No	9	45.0	45.0	100.0
Total	20	100.0	100.0	

4.1.3 The respondents job titles

The questionnaire was addressed to the managing director of each company, with a covering letter asking him/her to forward it to the appropriate person. Table 4.4 shows the distribution of the job titles of respondents. As we can see from the results about 15% respondent come from the design manager, 10% come from the owner or senior director, 75% come from different respondents such as Green designers, sustainability controller and Environment manager.

Anyhow, based on the results, we could say that the design mangers are well involved in eco-design process and the surveyed companies have yet to appoint a dedicated person to oversee the implementation of eco-design, WEEE and RoHS.

Table 4-4 Respondents job title

	Frequency	Percent	Valid percent	Cumulative Percent
Owner or senior director	2	10.0	10.0	10.0
Design manager	3	15.0	15.0	25.0
Other	15	75.0	75.0	100.0
Total	20	100.0	100.0	

4.1.4 The respondent job focus

Tables 4.5, 4.6, 4.7 shows respondents job focus, which tell us that about 85% of respondents focus in their job on environment, 60% job focus on manufacturing and 50% job focus on design.

This results shows that respondents job focus in their job on more than one area, which could lead us to conclude that in fact regardless of the job title of the respondents, we could say that design managers could be heavily involved in the effort of Eco-design than any other managers.

Table 4-5 job focus on environment

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	17	85.0	85.0	85.0
No	3	15.0	15.0	100.0
Total	20	100.0	100.0	

Table 4-6 job focus on manufacturing

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	12	60.0	60.0	60.0
No	8	40.0	40.0	100.0
Total	20	100.0	100.0	

Table 4-7Job focus on design

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	10	50.0	50.0	50.0
No	10	50.0	50.0	100.0
Total	20	100.0	100.0	

4.1.5 Type of product

Table 4.8 shows that 95% of respondents from the companies which manufacture and sell electrical and electronic equipments.

It was the intention of the questionnaire to examine companies from the electrical and electronic equipments, which will be involved in Eco-design and WEEE and RoHS

Table 4-8 Manufacture and sell EEE

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	19	95.0	95.0	95.0
No	1	5.0	5.0	100.0
Total	20	100.0	100.0	

4.2 Information about WEEE and RoHS

4.2.1 Products covered by WEEE and RoHS

Table 4.9 shows that 90% of respondents from companies covered by WEEE and RoHS and only 10% of respondents they do not know if they are covered or not.

Based on the results there are a strong respond to the WEEE and RoHS directive.

Table 4-9 Covered by WEEE and RoHS

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	18	90.0	90.0	90.0
Do not Know	2	10.0	10.0	100.0
Total	20	100.0	100.0	

4.2.2 Electrical and electronic product categories

Tables 4.10, 4.11, 4.12 and 4.13 shows that about 40% of respondents are from companies produce large and small household appliances, 40% of respondents are from companies produce IT equipment and telecommunication, 15% of respondents are from companies produce consumer equipment and 15% of respondents are from companies produce electrical and electronic tools.

Table 4-10Products are large and small household appliances

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	8	40.0	40.0	40.0
No	12	60.0	60.0	100.0
Total	20	100.0	100.0	

Table 4-11Products are IT equipment and Telecommunication

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	8	40.0	40.0	40.0
No	12	60.0	60.0	100.0
Total	20	100.0	100.0	

Table 4-12Products are consumer equipment

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	3	15.0	15.0	15.0
No	17	85.0	85.0	100.0
Total	20	100.0	100.0	

Table 4-13 Products are electrical and electronic tools

	Frequency	Percent	Valid percent	Cumulative percent
Valid Yes	3	15.0	15.0	15.0
No	17	85.0	85.0	100.0
Total	20	100.0	100.0	

4.2.3 Products contain hazard substances RoHS

Tables 4.14, 4.15 and 4.16 shows that 50% of respondents are from companies their products contain PCBs, 45% of respondents are from companies their products contain plastic parts more than 25g and 25% of respondents are from companies their products contain lead.

Based on the results PCBs, plastic parts more than 5g and lead are the most common hazard substances in the electrical and electronic equipments, but some products had cadmium, (PBB), (PBBE).

Table 4-14 Products contain RoHS like contain PCBs

	Frequency	Percent	valid Percent	Cumulative Percent
Valid Yes	10	50.0	50.0	50.0
No	10	50.0	50.0	100.0
Total	20	100.0	100.0	

Table 4-15 Products contain RoHS like plastic parts more than 25g

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	9	45.0	45.0	45.0
No	11	55.0	55.0	100.0
Total	20	100.0	100.0	

Table 4-16 Products contain RoHS like lead

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	5	25.0	25.0	25.0
No	15	75.0	75.0	100.0
Total	20	100.0	100.0	

4.2.4 Products contain materials, which required to be removed at end-of-life based on WEEE directive

Tables 4.17, 4.18 and 4.19 shows that 65% of respondents from companies their product contain batteries, 35% of respondents from companies their product contain toner, cartridges, liquid and pasty and 30% of respondents of companies their product contain external electric cables.

Based on the result the batteries are the most material required to be removed at end-of-life for separate treatment, as well as there is some other material need to be removed before the treatment like fluids, PCB greater than $10cm^2$, plastic containing brominates flame-retardants, CFC, HCFC, HFC, HC, liquid crystal displays of a surface greater than $100cm^2$, components containing refractory ceramic fibres and asbestos.

Table 4-17Batteries need to be removed at end-of-life

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	13	65.0	65.0	65.0
No	7	35.0	35.0	100.0
Total	20	100.0	100.0	

Table 4-18 Toner, cartridges, liquid and pasty needs to be removed at end-of life

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	7	35.0	35.0	35.0
No	13	65.0	65.0	100.0
Total	20	100.0	100.0	

Table 4-19External electric cables need to be removed at end-of-life

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	6	30.0	30.0	30.0
No	14	70.0	70.0	100.0
Total	20	100.0	100.0	

4.3 Preparing for the WEEE

4.3.1 Provide the re-used and treatment information

In order to prepare to join the WEEE directive, Table 4.20 shows that 75% of respondents came from companies which provided re-use and treatment information. Table 2.21shows that: 55% of the companies provided the information on line, 20% provided the information manually, 5% provided the information on CD-ROM and 20% provided the information on other ways.

Table 4-20 Producers provide reuse and treatment information

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	15	75.0	75.0	75.0
No	5	25.0	25.0	100.0
Total	20	100.0	100.0	

Table 4-21which way the information is provided

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Manual	4	20.0	20.0	20.0
CD-ROM	1	5.0	5.0	25.0
On-line	11	55.0	55.0	80.0
Other	4	20.0	20.0	100.0
Total	20	100.0	100.0	

4.3.2 Actions from producers to meet the WEEE directive

Based on the result on Tables 4.22, 4.23, 4.24, 4.25, 4.26 and 4.27 show that only 40% of respondents already register with WEEE directive, but in the same time there is 70% of respondents show that the producers meet the information and design requirements, 35% of respondents show that producers taking more proactive approach to sustainable design, 25% of respondents show that producers finance the collection, treatment, recovery and disposal of WEEE and 15% of respondents show that producers provide financial guarantees.

This result may represent a trend towards the Augmentation of eco-design to include WEEE and RoHS.

Table 4-22 Register

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	8	40.0	40.0	40.0
No	12	60.0	60.0	100.0
Total	20	100.0	100.0	

Table 4-23 Meet information requirements

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	14	70.0	70.0	70.0
	No	6	30.0	30.0	100.0
	Total	20	100.0	100.0	

Table 4-24Meet design requirements

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	14	70.0	70.0	70.0
	No	6	30.0	30.0	100.00
	Total	20	100.0	100.0	

Table 4-25 Take more proactive approach to sustainable design

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	7	35.0	35.0	35.0
	No	13	65.0	65.0	100.0
	Total	20	100.0	100.0	

Table 4-26 Finance the collection, treatment, recovery and disposal

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	5	25.0	25.0	25.0
	No	15	75.0	75.0	100.0
	Total	20	100.0	100.0	

Table 4-27Provide financial guarantees

	Frequency	Percent	Valid Percent	Cumulative Percent
Valid Yes	3	15.0	15.0	15.0
No	17	85.0	85.0	100.0
Total	20	100.0	100.0	

4.4 Data analysis

4.4.1 Data analysis methodology

One of the most important ways of summarising a distribution of values for a variable is to establish its central tendency. The term ‘central tendency’ refers to the ‘middle’ value or perhaps a typical value of the data. The three common approaches to describe the central tendency within a distribution are the mean, median, and mode. Each of these measures is calculated differently, and the one that is best to use depends upon the measurement scale of the data. For ordinal variables, calculation of the mean of a distribution of frequency of valuation response per factor would have no arithmetical logic. On the other hand, the mode as well as the median can be determined for ordinal data (Hilderband, 1977).

The following are the definitions of the median, mean and mode (Clarke, 1998):

-The median M of a set of N observations, which have been ranked in order of size is equal to the value taken by the middle (the $\frac{1}{2}[N+1]th$) observation when N is odd, and half the sum of the values of the two middle observations (the $\frac{1}{2}Nth$ and $\left[\frac{1}{2}N+1\right]th$) when N is even.

According to the above definition, the median ignores completely the actual sizes of the observations, except for those in the middle of the rank order. So, it is a measure of the centre of the observations not taking into account variations of sizes of those observations. Unlike the mean, the median is not influenced by outliers. For this reason, the median is often used when there are a few extreme values that could greatly influence the mean and distort what might be considered typical.

-The mean of a set of observations is the sum of the observations divided by the number of observations.

According to the above definition, the mean uses the actual values of all the observations, and is therefore particularly useful in detecting small differences between sets of observations. It has been found a convenient measure to use in the theory of statistics, whereas the median is usually not easy to deal with theoretically.

For the above reasons, the mean is the usual choice for a single measure to summarize a set of observations. It would be the natural measure to use in summarizing the observations of journey time.

-The mode of a discrete variate is that the value of the variate which occurs most frequently.

The mode can be very useful for dealing with ordinal and categorical data. However, a data set can have more than a single mode, and in this case the median may be best to use.

In addition, items in a question may have similar mode and median. In this case, ranking the items based on central tendency values only may not be very meaningful. One way, which could be employed in ranking the items, is a frequency distribution of the mode value. The idea of a frequency distribution is to provide information about the relative frequency of the occurrence of each category of a variable. However, a great deal of information is ignored when distribution of the mode is only considered (Pallant, 2004).

4.4.2 Measurement of variability

Statistics may be defined as the study of variability. If there were no variability there would be no need for the science of statistics. We look at ways of measuring the variability of populations and sets of observations (Clarke, 1998). The data values in a sample are not all the same. This variation between values is called dispersion. When the dispersion is large, the values are widely scattered; when it is small, they are tightly clustered.

The three common measures of variability are range, variance, and standard deviation. However, the variance and standard deviation are appropriate only for metric variables, which leave only range as appropriate for data which interval between responses is not measurably equal (Bryman, 1990).

Range' refers to a measure of the spread or the dispersion of the observations. Of all the measures of dispersion, the range is the easiest to calculate and to understand. It is simply the highest score or frequency minus the lowest. In other words, the range of a set of observations is the difference in values between the largest and smallest observations in the set (Clarke, 1998).

The range value may not allow a very informative structuring of the data for interpretation and other measures of spread are required to achieve ranking objective. In addition to the range, an inter-quartile range (IQR) can be used in relation to ordinal variables (Bryman, 1990).

IQR is a measure of the spread of or dispersion within a data set. It is calculated by taking the difference between the upper and the lower quartiles. Quartiles are values that divide a sample of data into four groups containing (as far as possible) equal number of observations. The IQR is the difference between the third and first quartiles, which contains the middle 50% of the sample, so it is less affected by outliers or extreme values. However, its chief limitation is that in ignoring 50% of the values in a distribution it loses a significant amount of information (Clarke, 1998).

4.4.3 Critique on ranking ordinal data

Ranking the items based on central tendency values only may not be very meaningful. Therefore, the two measures of central tendency (i.e. mode and median) combined with the inter-quartile range will determine more precisely the perspective of the research sample and the valuation given to gain further insight into the ordering of the items. IQR was chosen instead of index of diversity and variation ratio, because it is easy to count in SPSS programme, which been used to help in the analysis of this research as a well respected and recognised tool.

The data analysis that is presented in this and the following chapter are restructured and grouped based on relevancy. The analysis is comprehensive and includes all questions asked. Mode, median, mean, range and inter-quartile range (IQR) are used in the analysis where applicable.

4.4.4 Descriptive analysis data used in this research

As mentioned data from questionnaire, were coded and entered into SPSS 14 for analysis. The 'I do not know' item was added to the scale in order to give respondents an opportunity to choose if they were not sure, so that their answer may help to increase the accuracy of the data.

The six-point scale from 1 to 6 (from do not know to a very great extent) is used for analysis only. The idea behind the scale 0 to 6 scale is to enhance the reliability and accuracy of the data collected by encouraging the respondents to give their answer some more thought rather than going straight to the middle value.

The 'not at all' point is included in the scale and analysis for the following reasons:

First, the scale is ordinal in nature and the difference between its items is not fixed. For instance, the difference between 'limited extents' to 'moderate extent' in the respondents scale is not similar to the difference between 'not at all' and 'limited extent'.

Second, 'not at all' it is put in scale because the research deals with different types of companies and organisations (small, medium and large). Therefore, some questionnaire items may not be relevant in some situations. So, choosing 'not at all' is the right choice for both respondents and research results and reliability.

In this chapter, the analysis results of the following parts are presented as follows:

- Tools for Eco-design
- Eco-design external information sources
- Design considerations

4.5 Eco-design tools

Based on a detailed literature review in chapter (2), we divided in to four sections as follows:

- Tools for environmental analysis and instruction
- Tools for creativity techniques
- Tools for setting priorities and decision-making
- Tools for cost accounting

4.5.1 Tools for environment analysis and instruction

In Question 12, respondents were asked to rate the extent their organisations are employing the listed tools when it comes to designing products. The list of tools and descriptive analysis results are shown in Table 4.28.

The main reason for asking this question is to find out what tools respondents are using to design their products in general, and whether they are or not already employing some of these tools, which help in designing environmentally products.

This is very important to aims and objectives of this work.

4.5.1.1 The analysis result of tools for environmental analysis and instruction

At a glance at Table 4.28, we could see that most of the respondents are using the traditional tool for product design as check lists (mode =6and median=4.50), and we could see as well the WEEE directive is being used from moderate extent to very great extent based on (mode=6, median=4), and LCA is being used from moderate extent to great extent based on (mode=5 and median=4).

As seen from the Table, using traditional tools for design is not wrong, but those tools were originally developed without environmental concerns or as we know environment now encourages WEEE and RoHS directives, which will be very essential in the future. So, in order for organization to design green products, tools such as MET matrix, Eco-design check list and the rest of the listed tools should be used to enhance the traditional tools for design or replace them all together.

Finally, our respondents in this research have highlighted once again that internal factors rather than external ones are hindering the progress, which could be achieved in the field of eco-design. Education and training is the key for progress. Then having the courage to experiment with new tools is the way forward.

Table 4-28Tools for environmental analysis and instruction

Tools for environmental analysis and instruction	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
LCA	20	0	3.65	4.00	5	5	3
MIPS Analysis	20	0	2.10	2.00	2	4	1
CED analysis	20	0	1.50	1.50	1	1	1
MET Matrix	20	0	1.60	2.00	2	2	1
Eco-Compass	20	0	1.50	1.50	1	1	1
Checklists	20	0	4.05	4.50	6	5	4
ABC-analysis	20	0	2.15	2.0	2	5	1
Eco-Estimator	20	0	1.55	1.50	1	2	1
Eco-Checklist	20	0	1.55	1.50	1	2	1
WEEE directive	20	0	3.75	4.00	6	5	4
Checklist for recyclable fittings and joint engineering	20	0	3.05	2.50	2	5	2

4.5.2 Tools for creativity techniques

In question 13, respondents were asked to rate the extent their organization are employing the listed tools when it comes to designing their products.

The list of tools and descriptive analysis results are shown in Table 4.29.

4.5.2.1 The analysis result for tools for creativity techniques

The only tool used in this section comparing with the other tools is classical brainstorming based on the result (Median =5 and mode=6).

The analysis result of this section came in a complete harmony with the previous one. This would confirm both reliability of answers and the lack of utilising tools, which are meant to help and facilitate implement the WEEE and RoHS directives.

Instead our respondents are only using the traditional classical brainstorming, which has its own disadvantages. Once again the researcher feels that respondents' answers based on either not knowing the listed tools or do not know how to use them. In order for companies to progress in eco-design and WEEE and RoHS, they have to be using proven up to date tools and techniques.

Table 4-29 Tools for creativity techniques

Tools for creativity techniques	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Classical brainstorming	20	0	4.85	5.00	6	5	2
Brain writing	20	0	2.05	2.00	1	3	2
Bionics (coping from nature)	20	0	1.85	2.00	2	3	1
Heuristics principles	20	0	2.00	2.00	2	3	1
The morphological box	20	0	1.50	1.50	1	1	1
Progressive abstraction	20	0	1.45	1.00	1	1	1
TRIZ	20	0	1.50	1.50	1	1	1

4.5.3 Tools for setting priorities and decision-making

In question14, respondents were asked to evaluate to what extent their organisations are utilising a list of popular tools for setting priorities and decision-making when it comes to designing their products.

The list of tools and descriptive analysis results are shown in Tables 4.30

4.5.3.1 The analysis result for the setting priorities and decision making

At a glance at Table 4.30, we could see respondents are utilising to a moderate extent the traditional checklist for selecting new solution based on (mean=3.30 and median =2.50).In fact it is perhaps the only one they used, as the rest of the tools reported as not applicable. Once again, according to the results there is lack of knowledge of such tools and their reported great benefits.

The researcher strongly feels that the answers are reliable and come in harmony with the other answers in the survey.

Table 4-30 Tools for setting priorities and decision-making

Tools for setting priorities and decision-making	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Checklist for selecting new solution	20	0	3.30	2.50	1	5	4
Eco-design matrix	20	0	2.05	1.50	1	4	2
Eco-design portfolio	20	0	2.10	1.50	1	4	2
Quality profile	20	0	1.90	1.50	1	4	1
Dominance matrix of paired comparison	20	0	1.55	1.00	1	4	1
HoEQ (House of Environmental Quality)	20	0	1.35	1.00	1	1	1

4.5.4 Tools for costing accounting

This section should be the most important sections in this work for respondents, as it is the difference between loss and profit. As a large number of our respondents might be thinking that Eco- design, WEEE and RoHS could mean loss and out of business due to the lack of financial support for such a programme. The way organisations calculate their cost and profit is very important.

In question 15 respondents were asked to rate to what extent their organisations employ the listed tools when it comes to designing products.

The descriptive analysis of this section is presented in Table 4.31

4.5.4.1 The analysis result for tools for costing accounting

As shown in Table 4.31, respondents are using (TCA) based on (mode=4, mean=3.75 and median=4), and using life cycle costing (LCC) based on (mode=4, mean=3.25and median=4). The other tools is not being utilised by our respondents. This could be one of the reasons, which organisations are not taking up eco-design with enough enthusiasm to push such a programme forward like WEEE and RoHS. Companies will not see the benefit of eco-design for themselves or for the environment unless they account for it properly by using the up to date tools. Once again the researcher feels that companies are not aware of what is out there in the field of eco-design in terms of tools.

Table 4-31Tools for cost accounting

Tools for cost accounting	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Benefit analysis	20	0	3.25	3.00	1	5	4
TCA (total cost accounting)	20	0	3.75	4.00	4	5	2
LCC (life cycle costing)	20	0	3.25	4.00	4	4	3
FCA (full cost accounting)	20	0	2.80	2.00	1	5	4
Cost accounting and eco-design	20	0	1.95	2.00	2	4	1

4.6 Eco-design external information sources

In question16, respondents were asked to rate the importance of a list of Eco-design external information sources to their organisations.

Table 4.32, lists the external sources and the descriptive analysis for each sources.

4.6.1 The analysis result for Eco-design external information sources

At a glance at Table 4.32, the first sources of information for almost all respondents comes from the Internet based on (mean=5, median=6 and mode=6), then you will see the other sources like government publications and publications, journals, hand books and contact with industry group.

Naturally contact with relevant authorities such as the environmental agencies come first as well, but the answers come up with (mean=4.15, median=4 and mode=3).

Once again the companies should seek information from every available resource without discrimination. As it is important for companies to have a total knowledge of what is going on in the field of eco-design and keeping up with changes and new legislations like WEEE and RoHS. The respondent in our research discriminate between different sources of information. As there answers vary from limited extent to a very great extent. This way of gathering information could be understandable in the old way of doing things, but in this day and age, the variety of information sources should be considered and used, as any information is important and in some cases is very significant.

Table 4-32Eco-design external information sources

Eco-design external information sources	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Publications, journals, handbooks and books	20	0	4.25	4.50	5	5	2
Contact with relevant authorities	20	0	4.15	4.00	3	5	2
Visiting workshops/seminar /meetings	20	0	3.70	4.00	4	4	2
Contact with industry group	20	0	4.30	4.50	5	5	2
Advice from consultant or insurance company	20	0	3.50	4.00	4	4	3
TV, radio and newspapers	20	0	3.10	2.50	5	4	3
Internet	20	0	5.00	6.00	6	5	2
Government, industry, business publications	20	0	4.35	5.00	5	5	1
University	20	0	2.60	2.00	2	4	1

4.7 Design considerations

In our research we divide the design consideration to six parts as follows

- Environmental concerns
- System design
- Material sourcing
- Manufacturing and distribution
- Use
- End-of-life

4.7.1 Environmental concerns

There are growing pressures and incentives for business to improve its environmental performance, respondents in this research were asked in question 17 to rate the extent to which reasons they are considering the environment in their organisations.

The descriptive analysis results are in Table 4.33

4.7.1.1 The analysis results for the environmental concerns

As shown in Table 4.33, respondents consider to a very great extent, based on (median=6 and mode=6) come up from customer requirements and environmental load.

But Regulatory requirements result was (median=4.50 and mode =6), this because when it comes to environmental legislations there are fear of extra cost or drop in profit, their ability to comply with such regulations, but there is lack of proper guidance and information in this field and lack of proper qualified staff.

Respondents overwhelmingly agreed that the above issues are all-important and need to be addressed in order for their organisation to go forward.

Table 4-33 Environmental concerns

Environmental Concerns	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Regulatory requirements WEEE/RoHS	20	0	4.55	4.50	6	5	3
Customer requirement	20	0	4.90	6.00	6	5	2
Environmental load	20	0	4.55	6.00	6	5	3

4.7.2 System design

In Question 18, the researcher presented respondents with a list of principles that constitute both materials and components recovery. Respondents were asked to rate the extent their organisations take into account these principles when it comes to design for disassembly or recycling or reuse.

The descriptive analysis result is presented in Table 4.34

4.7.2.1 The analysis results for system design

According to the descriptive analysis in Table 4.34, the principles of system design are ranked as follows:

- Based on (median=6, mode=6 and IQR=1) respectively, using common parts in different designs rank first.
- Based on (median=5, mode=5 and IQR=0&1&2) respectively, reduced complexity of enclosures and assemblies, fewer parts, multifunctional parts and source reduction considered rank second
- Based on (median=4.50, mode=5 and IQR=3) respectively, Multifunctional product rank third.
- Based on (median= 3, mode=5 and IQR=3) respectively, longevity considered rank forth.

Based on the above ranking, respondents are not taking into account the system design to a very great extent when designing their products, but in the same time respondents' results come up to a great extent.

Design for disassembly, recycle or reuse which is important to implement WEEE and RoHS directive cannot be considered at the end-of-life of products, but it should be built into the very first stages of product's design. Attention should then be paid to all aspects of the product from materials selection down to types of adhesives used. In general our respondents should work a lot harder into their design policy.

Table 4-34 System design

System design	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Reduced complexity of enclosures and assemblies	20	0	5.05	5.00	5	5	1
Fewer parts	20	0	5.00	5.00	5	5	1
Multifunctional parts	20	0	4.90	5.00	5	5	0
Using common parts in different designs	20	0	5.35	6.00	6	5	1
Multifunctional products	20	0	4.10	4.50	5	5	3
Is longevity considered	20	0	3.35	3.00	5	4	3
Is source reduction considered	20	0	4.15	5.00	5	5	2

4.7.3 Material sourcing

In Question 19, 20 and 21 researcher asked the respondents to rate to what extent their organisations take them into account when it comes to material sourcing within their design context, the researcher asked about three types of material if it is considered in the product's design, recycled material, hazard material and scarce resources.

The descriptive analysis results are presented in Table 4.35, 4.36 and 4.37

Table 4-35Material sourcing (recycled material)

Recycled material	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Recycled materials specified for product materials	20	0	3.25	4.00	5	4	4
Recycled materials specified for packaging	20	0	4.30	5.00	6	5	3

Table 4-36 Material sourcing (hazard materials)

Hazard material	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Hazard materials avoided	20	0	4.70	5.00	6	5	2
Hazard materials minimized	20	0	4.25	4.50	4	5	2

Table 4-37 Material sourcing (scarce resources)

Scarce resources	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Scarce resources avoided	20	0	3.55	3.50	1	5	3
Scarce resources minimised	20	0	3.35	3.00	1	5	4

4.7.3.1 The analysis for Material sourcing

At glance at Table4.35, we could see that recycled materials specified for packaging had a great extent rate, while recycling materials specified for product materials had a moderate extent rate. This is explained that our respondents aren't taking into account the recycled material during the manufacture and design product stage, using all recyclable materials is an excellent contribution to the environment, but only a moderate attention is paid to use all recycled materials. So, we would like to see respondents using more of recycled materials where possible.

According to the descriptive analysis in Table 4.36, there is avoiding to the hazard material based on (median=5, mode =6), and minimizing the hazard material based on (median=4.50, mode=4).

Again reducing hazardous materials should be taken into account at the manufacture, usage stages and during the end-of-life stage, respondent in this survey come up with a moderate extent rate for minimized the hazardous material and a great extent rate for avoided the hazardous materials.

In Table 4.37, respondent's results rate to a limited extent in both avoided and minimised the scarce resources, again this is explained that our respondents aren't taking into account the scarce resources as a very important and valuable issue, lower material use whether recycled or raw is always environmentally beneficial.

From all the above results the researcher find that the companies they are not taking into account the material sourcing from the beginning of the design.

4.7.4 Manufacturing and Distributions

In Question 22, the researcher asked the respondents to rate to what extent their organisations take them into account when it comes to energy conservation, minimise the air and water pollution and minimise the water and material use during the manufacturing and distribution.

The descriptive analysis presented in Table 4-38

Table 4-38 Manufacturing and distribution

Manufacturing and distribution	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Energy conservation in manufacturing	20	0	4.05	4.00	6	5	3
Energy conservation in distribution	20	0	3.10	3.00	4	4	2
Waste minimisation in manufacture	20	0	4.50	4.50	4	5	2
Minimise the air and water pollution	20	0	4.40	5.00	5	5	3
Minimise the water and material use	20	0	3.80	4.00	4	5	2

4.7.4.1 The analysis for the manufacturing and distributions

According to the results in Table 4-38, energy conservation in manufacture, waste minimisation in manufacture, minimise the air and water pollution and minimise the water and material use had from moderate extent rate to a very great extent, only the energy conservation in distribution had a limited extent rate.

Respondents are making some progress but a lot more can be done towards manufacturing and distribution without damage the environment; companies are not giving serious attention to reducing and improving energy utilization where possible.

4.7.5 Use

In Question 23, the researcher asked the respondents to rate to what extent their organisations take into account some principles during the design stage to be environmentally friendly during use stage, such as:

- Minimum power consumption in use
- Minimum packaging
- Minimum consumable use

- Minimum waste consumables in use (batteries)
- Serviceability, longevity and durability

The descriptive analysis presented in Table 4.39.

4.7.5.1 The analysis of Use

According to the result in Table 4.39, the descriptive analysis shows that there is moderate extent to great extent to most of the principles.

The companies should take into account the use stage as an important stage because its affect the environment as the manufacturing stage.

Table 4-39Use

Use	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Minimum power consumption in use	20	0	4.65	5.00	4	5	2
Minimum packaging	20	0	4.00	4.00	4	5	2
Minimum consumables use	20	0	4.50	5.00	4	5	2
Minimum waste consumables in use	20	0	4.10	4.00	4	5	3
Serviceability, longevity, durability	20	0	5.00	5.00	6	5	2

4.7.6 End-Of-Life

In Question 24, 25, 26 and 27, the researcher asked the organisations to rate their considerations at the end of the product life cycle, and are they taking into account their products could be recycled, disposal, reuse and so on.

The descriptive analysis presented in Table 4.40, 4.41, 4.42 and 4.43

Table 4-40Design for disassembly and components recovery

End-of-life	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Design for non-destructive removal	20	0	4.05	4.00	4	5	2
Design for speedy diagnosis and refurbishment	20	0	4.60	5.00	5	5	2
Design for close loop manufacture	20	0	2.75	3.00	1	4	3
Design for secondary applications	20	0	3.30	3.00	4	5	4

Table 4-41 Material recovery

End-of-life	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Is there market for the removed material	20	0	3.75	4.00	5	5	3
Is there a separation and recycling technology and infrastructure	20	0	3.75	4.00	4	5	3
Is there any other requirement for material separation RoHS	20	0	3.95	4.00	4	5	3

Table 4-42Material sorting

End-of-life	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Material combinations compatible for recycling	20	0	3.95	4.00	6	5	3
Use of recyclable materials	20	0	4.45	4.00	4	5	2
Grouping hazardous or non recyclable components	20	0	3.05	2.50	1	5	4
Use of standard screw heads	20	0	5.00	6.00	6	5	2
Use of detachable leads and push in plugs	20	0	4.40	5.00	6	5	4

Table 4-43Assembly/Disassembly methods

End-of-life	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Is the component assembly designed to ease of assembly	20	0	4.55	5.00	5	5	1
Simple component mechanism and orientation	20	0	3.65	4.00	4	4	2
Provision of grasping parts	20	0	3.80	4.00	5	5	3
Use of screws in preference to rivets	20	0	4.85	5.50	6	5	2
Snap fit for spring clips in preference to threaded fasteners	20	0	4.50	4.50	4	5	2
Common fasteners	20	0	4.55	5.00	4	5	2

4.7.6.1 The analysis of end-of-life

According to the result in Tables 4.40, 4.41, 4.42, 4.43, the descriptive analysis shows that there is limited extent to moderate extent or great extent to most of the considerations. Our respondents are not fully incorporating the end-of-life assessment into their designs.

For example: from the previous questions we notice a great effort is given by respondents to reduce the amount and effect of hazardous materials during both manufacturing and usage but not at End-of-life of product by grouping the hazardous materials.

In order to produce environmentally friendly products and implement the WEEE directive, our respondents where possible have to incorporate all the considerations of end-of-life into their design programme and company policy, and this is could be done by implement the Eco-design as an important tool to implement the WEEE and RoHS directives easily.

4.8 Design for X (DFX)

DFX is a term that is used to represent a variety of considerations that must be made whilst designing a product. All of the listed DFXs could come under the umbrella of eco-design. The collection of different design considerations could be used as required by the objectives of every different specific design.

In question 28, the respondents were asked to rate to what extent they utilize the following principles and considerations when it comes to designing products:

- Design for assembly (DFA)
- Design for disassembly (DFD)
- Design for manufacture (DFM)
- Design for Quality (DFQ)
- Design for recycling (DFR)
- Design for serviceability (DFS)
- Design for testability (DFT)
- Design for up-grade (DFUG)

4.8.1 The analysis results for Eco-design considerations [Design for X family (DFX)]

The descriptive analysis of eco-design considerations (DFX) is presented in Table 4.44.

In this day and age, and in a country such as UK, which is trading globally, companies are expected to design and manufacture high quality products, which fulfil customer's needs and wants. So, our respondents are well aware of designing quality products and therefore following internationally recognized format when doing so.

Table 4.44 shows that our respondents are making a very great use of design for quality (DFQ) consideration based on a median=6 and a mode=6. This result confirms and consolidates the reliability of answers provided by respondents in this research.

To sum it all up, our respondents are very good when it comes to quality and other traditional design considerations such as DFM, DFS, and DFT.

However, they are lingering behind when it comes to design considerations, which could help in the implementation of WEEE and RoHS directives such as DFR, DFUG and DFD.

So, environmentally conscious companies are expected to make an excellent use of all the listed DFX.

Table 4-44 Design For X

Eco-design consideration (DFX)	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Design for assembly (DFA)	20	0	4.30	5.00	5	5	3
Design for disassembly (DFA)	20	0	3.55	5.00	5	4	4
Design for manufacture (DFM)	20	0	4.45	5.50	6	5	3
Design for quality (DFQ)	20	0	4.75	6.00	6	5	2
Design for recycling (DFR)	20	0	3.50	4.00	5	5	4
Design for serviceability (DFS)	20	0	4.20	5.50	6	5	5
Design for testability (DFT)	20	0	4.50	5.00	6	5	2
Design for up-grade (DFUG)	20	0	3.10	3.00	1	4	4

4.9 Management System

This part was divided into three questions. In question 29, the respondents were asked to confirm whether they have or have not received a certification in any of the listed ISO standards or other related standard, Table 4.45 lists the standards and the results of the analysis. In question 30, the respondents were asked to confirm whether their organisations plan to achieve any certification or validation related to their Eco-design or WEEE in the next two years, Table 4.46 lists the results of the analysis. In question 31, the respondents were asked to evaluate the importance of listed reasons, which drove their organisation to implement a management standard, Table 4.47 lists the results of the analysis.

Table 4-45 International certifications

International Certification	Yes	No
ISO 9000	19	1
ISO14000	15	5
ISO 14001	10	10
ISO 14040	1	19
ISO 14020	0	20

Table 4-46 Planning to achieve any certification or validation related to Eco-design or WEEE

	Frequency	Percent	Valid percent	Cumulative percent
Yes	9	45.0	45.0	45.0
No	5	25.0	25.0	70.0
Do not know	6	30.0	30.0	100.0
Total	20	100.0	100.0	

Table 4-47 Ranked reasons for implement management standards

Reasons considered important to management standards	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Facilitating compliance with eco-design legislation	20	0	3.95	4.00	4	5	2
Facilitating compliance with WEEE and RoHS	20	0	4.85	5.00	6	5	2
Required by customer	20	0	4.75	5.00	5	5	2
Competitive advantage	20	0	5.15	6.00	6	5	2
Trade and International Trade	20	0	3.90	4.50	5	5	4
Overseas Parent company	20	0	4.50	5.00	6	5	4
Eliminate non-conference results	20	0	4.45	5.00	5	5	1
Improve eco-design performance	20	0	3.95	5.00	6	5	5

4.9.1 The analysis result of international certification

As shown in Table 4.45, nearly all respondents have achieved ISO 9000 and 50% of respondents achieved ISO 14001, which is good indication of the quality of respondents. It shows that respondents have successful experience in implementing quality management standards, which could help them in implementing and achieving environmental management standards certifications, but in the same time there is other respondents for ISO 14000 and ISO 14040 which is accurate as the other standards but don't carry certificate, Here the researcher wanted to check the knowledge of the respondents.

As shown in Table 4.46, 45% of respondents answered yes to question 30, which is an encouraging result, and it highlights a great interest in Eco-design and WEEE among companies.

As shown in Table 4.47, competitive advantages ranked as the highest reasons for implementing management standards, then facilitating compliance with WEEE and RoHS, overseas parent company and improve Eco-design performance takes the second place for implementing management standards, that could be due to infancy of the eco-design programmes among most of respondents, and all of them already implenentedISO9000 or parts of it before attempting any environment standards.

4.10 Legislation

4.10.1 Environmental legislation issues

This section contain two questions, question 32, 33

In Question 32, respondents were asked to rate the extent to which their organisations face the following issues and problems, when it comes to environmental regulations and legislations.

The descriptive analysis results for these ten issues are presented in Table 4.48

Table 4-48 Environmental legislation issues

Environmental legislation issues	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Compliance with regulations WEEE and RoHS	20	0	4.60	5.00	6	5	2
Communication & implementation of these regulations in organisation	20	0	4.25	4.50	5	5	1
Insufficiency of eco-design legislation and regulation	20	0	2.85	3.00	3	4	3
Interference and conflict between authorities	20	0	2.90	2.00	2	4	3
Recognition of importance of eco-design of eco-design within organisation	20	0	3.80	4.50	5	5	3
Leadership attention/ responsibilities	20	0	3.95	4.50	6	5	4
Insufficient data resources	20	0	2.70	2.00	2	5	2

4.10.1.1 The analysis resultsfor environmental legislation issues

As shown in Table 4.48, respondents agreed that the above issues are important and need to be addressed in order for their organisation to go forward. We could see that the above issues are mostly internal issues rather than external.

Another internal issue is the recognition of the importance of eco-design within the organisation itself, respondents reported this issue as having a great effect (mode=5, median=4.50) on their environmental programmes.

Then, respondents regard interference and conflict between different legislation and authorities, insufficient data resources, and once again another internal problem, top management commitment would have a limited effect on their programme bases on (mode=2 and median =2).

Finally, we notice that issues and problems facing then when it comes to environmental legislations are fear of extra cost and/or drop in profit, their ability to comply with such regulations, lack of proper guidance in this field by insufficient environmental regulations, lack of qualified staff, and resistant to change from traditional methods.

4.10.2 Suggestions to improve authorities

The second question in this section aims to evaluate several approaches to improve the authorities' role in enhancing eco-design programmes, which normally leads to the implementation and complying with different environmental legislations such as WEEE and RoHS.

In question 33, respondents were asked to rate the importance of a list of suggestions regarding additional help they might like to receive from authorities in relation to environmental issues.

The descriptive analysis results for these issues are presented in Table 4.49

Table 4-49 Suggestion to improve authorities' role

The role of authorities	Valid No	Missing Data	Mean	Median	Mode	Range	IQR
Clear simpler regulations	20	0	5.40	6.00	6	3	1
Aim-target regulation rather than detailed legislation	20	0	4.30	4.00	4	5	2
Adoption of international legislation and guides	20	0	4.55	5	4	5	2
Providing more education/information and training	20	0	4.00	4.00	4	4	2
Establishing a national data base	20	0	4.10	4.00	4	4	2
Establishing national guide for managing Eco-design	20	0	3.80	3.50	3	5	2

4.10.2.1 The analysis results for suggestions to improve authorities' role

The general trend and perceptions among respondents is that a lot could be done to improve the role of authorities. After all, legislations are set and imposed by authorities, and then concerned organisation' compliance is tested, and enforced by the same authorities.

So, based on the analysis results, authorities would have to do more to help organisations to implement and comply with different environment legislations. Respondents rate strongly the listed suggestions, and taking them in to account by relevant authorities could help immensely UK companies in their quest for implementing and complying with different legislations.

4.11 Discussions on data analysis

This chapter presents the data analysis results and detailed discussion for each section. The finding grouped and summarized in order to help the researcher in suggesting strategies and framework for companies in their quest to implement environmentally friendly practices namely eco-design to include the WEEE and RoHS directive.

The damage to the environment is fact of life, but our duties are to lower, limit and control such damage in order for future generations to enjoy happy life on our beloved plant earth.

CHAPTER 5 APROPOSED PLAN-DO-CHECK-ACT (PDCA) FRAMEWORK FOR WEEE AND ROHS

This Chapter presents the proposed framework for WEEE and RoHS implementation and integration into business's operation and strategy. The framework developed in this research is based on a comprehensive and detailed literature review, which is presented in Chapters two of this work, the data analysis results of the survey as presented in Chapters four of this work, and the researcher's own understanding and experience in the subject of Eco-design.

The main objective of the framework is to provide a roadmap for interested companies to successfully kick-start their Eco-design programme or improve an existing one by helping them to produce environmentally friendly products and integrate WEEE and RoHS directives programme in the business operation and strategy, thus guaranteeing a fair chance of success. So, this framework and the associated implementation plan are developed to provide businesses with important tools and activities related to Eco-Design, which could then be deployed by businesses to help to take into account WEEE and RoHS directives for producing environmentally friendly products. It is not the intention of this framework to teach business on the pure specifics of products' design, but rather on what Eco-Design principles and rules should be observed during the engineering design process and its related activities. The author believes that designers given the required resources, information and training will be able to observe and take into account such rules and principles and consequently design products, which causes less impact on the environment.

The framework is based on Deming's PDCA improvement cycle. The rationale behind using PDCA cycle as a basis of the framework is presented in this Chapter along with summary explanation about the PDCA cycle itself.

5.1 Consideration of various options

The most popular process diagrams:

- the traditional process diagrams with and without a feedback loop;
- tree diagram;
- turtle diagram;
- pyramid diagram;
- six sigma;
- PDCA Cycle diagram.

The Traditional Process diagram, Tree diagram, Turtle diagram and Pyramid diagram are more or less one-way process diagrams and not meant to cater for processes requiring continuous feedbacks and therefore do not support a continuous improvement process as it is wanted in this work.

Just to avoid confusion, the Six Sigma process is meant to aid in the improvement of existing processes rather than be a map for new processes. Thus, the fundamental objective of the Six Sigma methodology is the implementation of measurement-based strategy that focuses on process improvement variation reduction through the application of Six Sigma improvement projects.

Among other uses, PDCA cycle is used successfully in, the implementation of Total Quality Management (TQM) programmes (Kanji, 1996), organizing Quality Management System's (QMS's) management review process and help focusing on specific organizational needs (Omens, 2006), helping auditors in process auditing (Russell, 2006), continuous improvement in service organisation (Baker and Artinian, 1985), achieving quick market acceptance for products (Meyer, 2003). The freight industry has used PDCA in order to improve and control its administration process (Benneyan and Chute, 1993). Today, the ISO 9001 quality management standard specifies the use of the PDCA model for managing processes and creating process oriented thinking (Gupta, 2006). Moreover, PDCA is used to provide a method for the implementation of ISO 14001 Environmental Management System (EMS) (Kinsella and McCully, 1999).

Thus, PDCA Cycle seemed to be a natural choice for the implementation of Eco-Design process in this work.

5.1.1 The Plan-Do-Check-Act (PDCA) Cycle

Plan-Do-Check-Act (PDCA), often called the Deming Cycle or the Shewhart Cycle, improves decision making by translating scientific hypotheses testing into management proposed plans. PDCA is unique as a decision-making tool because it requires that plans be tested on a small scale before they are implemented system wide. This supports the concept of the prevention of defects. PDCA also builds continuous improvement into planning through data collection on the effectiveness of the new process of change. PDCA can serve as a catalyst for the practice of scientific management in an organization. The process also enables organizations to search for and address root causes of problems. PDCA utilizes the 7 statistical tools of quality and also allows the application of the 7 new management tools of quality (Bushell, 1992, Harman, 1989, Selden, 1999).

W. Edwards Deming developed the PDCA Cycle in the 1940s and 1950s as a strategy to build improvement in manufacturing. The strategy is: 1. Plan to do something. 2. Do it, 3. Check the results, and 4. Adapt (Meyer, 2003). PDCA Cycle would then repeat itself, and that is why Dr. Deming PDCA Cycle is known to improve any cycle of activity (Selden, 1999). An example of a typical PDCA cycle is shown in Figure 5.1 (Gupta, 2006).

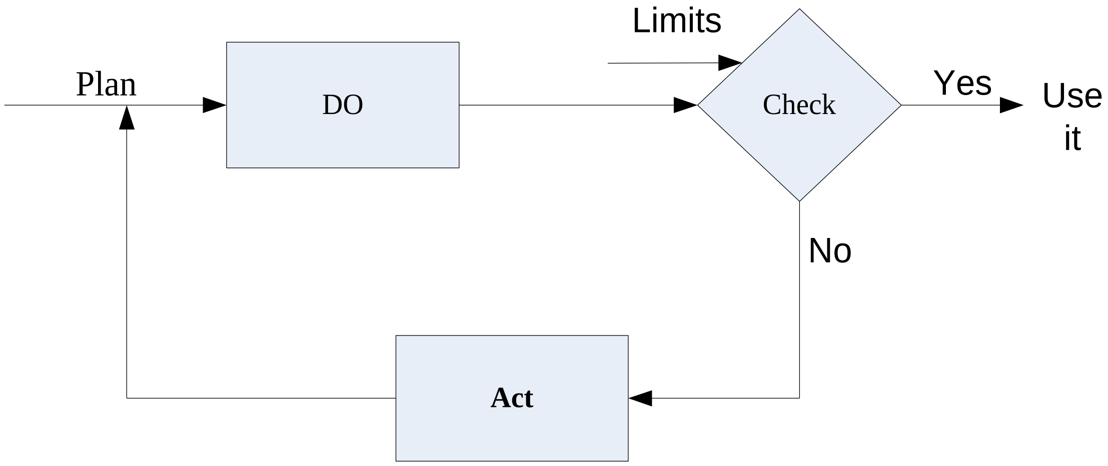


Figure 5- 1 Dr. Deming's PDCA cycle (Gupta, 2006)

The general concept of the PDCA Cycle is outlined in Table 5.1 (Benneyan and Chute, 1993)

Table 5- 1 Dr. Deming's Plan, Do, Check, Act Process Improvement Cycle

Address each phase of the PDCA Cycle before beginning an improvement project and again at the start	
Plan	What do we hope to gain (be specific)? What is the scope of this project? What can we *do*, *check*, and *act* on this project? How much should be done before checking the results, How much should be checked before acting on conclusions, and how much should be acted upon before planning the next cycle? What constraints are involved? How long should each step take? Who should be involved? Plan the change or activity. Allocate time, money, personnel, and authority for the project. What should be measured? How? When?
Do	Perform the activity identified in the *plan* stage, preferably in a small-scale study. Hold meetings. Get suggestions. Train those involved in the necessary skills. Make changes.

	Collect and analyse data.
Check	What was the result of the *do* phase? Is it what we expected? Monitor the effects, checking for side effects and backslidings. Interpret the results. What conclusions can be inferred? What do these conclusions mean to this process? If the *do* was a process change, did it result in an improvement? Results from statistical analysis in this check stage influence the *act* stage.
Act	Act on conclusions from the *check* phase. Should we continue working on this process? Collect more data? Get more suggestions? If the *do* was a process change for the better, standardize it. Adopt the change, refine it, or abandon it. How should we change the process now? Run through the cycle again, possibly under different environmental conditions.

5.1.2 The rationale behind using PDCA Cycle

In addition to the result of the review of other frameworks and models as presented in part 5.1 of this Chapter, the researcher has built the Eco-Design framework or roadmap utilizing the principles and steps of the PDCA Cycle due to the following justifications.

Eco-Design programme in this work is treated as a process. Eco-Design chances of success is better served by implementing it as a part of an organisation's wide continuous improvement programme, and thus integrating it into the business's normal operation and strategy, rather than an isolated activity. Furthermore, Eco-Design process is treated as a continuous improvement process with its own rights. It normally starts as a pilot scheme with modest objectives and then expands to other parts with rigorous objectives. The continuous improvement cycle in Eco-Design is a never-ending cycle.

Thus, the main aim of this work is to design a framework for Eco-Design that fulfils both the basic implementation requirements as set out in this work's literature review and help to implement the WEEE and RoHS directives, and to guarantee improvement continuity as an integral part of the organisations' normal operation and strategy leading to an effective management of the whole project.

5.2 Rationale and conceptualisation of the proposed framework

The proposed framework in this research is designed to offer a cure for the inherent lack of understanding of the problems facing the manufacturing industry, which manifest in dealing with the environmental concerns such as WEEE and RoHS directives and requirements as a troubleshooting issues and not a real challenge. The real challenge is the correct understanding and implementation of comprehensive Eco-Design programme not just parts of it to help to take in to account the WEEE and RoHS directives. Furthermore, the proposed framework is designed to fit nicely as a part of the company continuous improvement programme leading to integration in the normal business operation and strategy. In addition the proposed framework could be a basis for the implementation of ISO 14001.

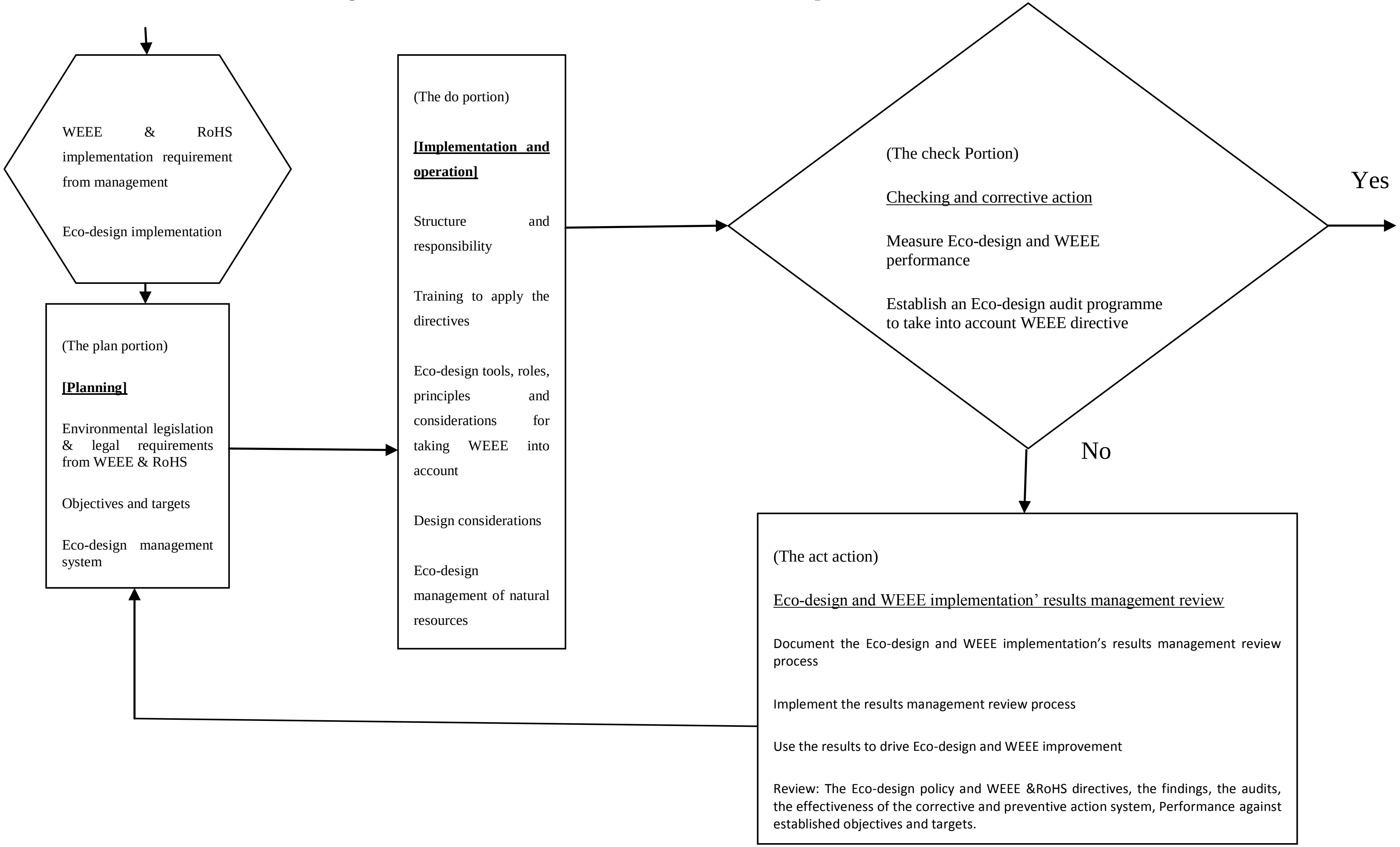
5.3 A description of the structure of the proposed framework

These high level requirements and factors formed the basis for the proposed framework for Eco-Design implementation. Then Dr Deming's PDCA improvement cycle basic framework was adopted to bring together all the vital factors and requirements for Eco-Design in a logical and effective sequences and loops.

5.3.1 An overview of the proposed framework for Eco-Design implementation

An overview of the proposed framework for Eco-Design and WEEE implementation is shown in Figure5.2.

Figure 5- 2 PDCA framework for WEEE and RoHS implementation into businesses



5.3.2 PDCA Eco-Design framework

The proposed Eco-Design framework is based on the literature survey and the research results of the study, discussed in the earlier Chapters of this work. The framework is based on the basic principles of Dr. Deming's PDCA improvement cycle, and the desired objectives of Eco-Design activities including implementation and integration. The proposed framework is designed to help manufacturing companies to deal easily and successfully with the new environmental requirements such as WEEE and RoHS Directives, reducing the CO2 emission, products' end-of-life issues and the restrictions on the use of natural resources (materials and energy).

The framework is based on PDCA improvement cycle principles, so companies could fulfil WEEE &RoHS and Eco-Design requirements as part of the company continuous improvement programme and not as a separate activity. The framework is designed to provide companies with a holistic understanding of the subject and implementation requirements of WEEE leading to full integration in the company's normal activities and strategy.

The framework is based on a careful literature survey and research analysis, so it provides companies with both an educating and guiding tool. The framework requires a team effort from all company's departments without exception with a solid top management commitment and involvement.

The framework together with the implementation plan provides a guiding force for companies to implement WEEE &RoHS directives on solid basis rather than on bits and pieces here and there and risk losing focus.

5.4 Critical factors in the framework

As shown in Figure 5.2, the main goal of the proposed framework is to produce environmentally friendly products and associated processes coupled with a continuous improvement programme, implement WEEE and RoHS Directives, and making Eco-Design an integral part of the business' normal operation and strategy. In order to achieve this goal, a holistic understanding of what is required and needed to attain this goal is provided in the framework.

The framework is based on the basic principles of Dr Deming’s PDCA improvement cycle, so it consists mainly of four stages with its associated sequences and loops.

The framework identifies the critical factors, which have a strong influence on the successful implementation of WEEE Directive. These factors are shown in Figure 5.2. Each stage or portion of the implementation plan has its critical success factors, which should be understood and implemented before moving on to the next stage. A detailed explanation about each critical success factor is presented in the implementation section in this Chapter.

5.5 The implementation plan for the proposed, PDCA Eco-Design Framework

The implementation plan of the proposed framework is conveniently structured into six sections of which are the four stages of the PDCA cycle as follows:

1. WEEE and RoHS requirement from management and Eco-design implementation
2. Planning (The Plan portion)
3. Implementation and operation (The Do portion)
4. Checking and corrective action (The Check portion)
5. Eco-Design implementation’s results management review (The Act portion)

An explanation about the above sections is presented in the following sections.

Implementation plan guidelines

Eco-Design is the systematic application of environmental considerations to product design, is likely to be most effective if considered WEEE and RoHS Directives, not as a separate exercise, but as part of an environmental management approach covering the company as a whole. Many of the issues relating to environmental management also apply to Eco-Design, since Eco-Design considers the environmental issues at all stages of the life cycle of a product, including its manufacture (Charter, 2006). The following are useful guidelines to help through the implementation phase.

- The implementation of WEEE and RoHS directives plan should be reviewed and understood in its totality before starting any activity.
- The implementation of Eco-design should be reviewed to take in to account WEEE and RoHS directives from the beginning.
- The implementation plan is based on a generic framework for Eco-Design, which could be utilised by different businesses regardless of the nature of the products. So, it does not intend to teach businesses on the engineering design specifics but rather on what should be observed and taken into account during the product design process in terms of WEEE and RoHS and Eco-Design must do activities including principles and rules.
- The various sections of the implementation plan would interact with each other.
- Users should use the implementation plan as a guiding force in their quest for Eco-Design and modify it where needed to suit implement WEEE and RoHS directives.
- The implementation plan should be considered as an integral part of the company wide continuous improvement programme, and looked at as a force to apply WEEE and RoHS Directives by integrate the Eco-Design programme into the business normal operation and strategy.
- A team from all departments should contribute in carrying out the implementation plan.
- Every employee should know the objectives of the implementation plan.
- The results of the data analysis of this work’s survey are used in the implementation plan, in order to learn from other experiences in WEEE and RoHS directives and Eco-Design.

5.5.1 Eco-Design, WEEE, RoHS implementation and Eco-design policy

The starting points should be an environmental review, which should identify and evaluate Eco-Design and supply chain issues alongside other aspects of environmental performance, and the scope for improvement. Such a review will form a basis for policy, objectives and targets, responsibilities and other management aspects, and a context for Eco-Design. It should also identify reasons, objectives and potential benefits of such programmes (CFSD, 2002).

All elements of Eco-Design must be implemented for the Eco-Design programme to be a successful fully functioning system. It is quite normal for a company or organisation to believe that they have an Eco-Design programme in place where in fact, they only have parts of an Eco-Design programme. Thus, excellent and thorough preparation for Eco-Design would most definitely pave the way to a smooth and effective implementation. Table 5.2 is a checklist of prerequisites for companies and organisations to use as they begin their journey toward establishing an Eco-Design programme.

Table 5- 2 Checklist of prerequisites for Eco-Design programme

Checklist of prerequisites for Eco-Design implementation:

1. Get and establish 100% top management commitment.
2. Establish an Eco-Design core project implementation team, sometimes called steering committee (must be cross functional to ensure wide involvement)
3. Prepare project plan
4. Identify project objectives
5. Define project scope
6. Document justification for project
7. Develop project schedule
8. Assign resources for project
9. Perform gap analysis where applicable
10. Establish project reporting process
11. Seek external help and guidance as necessary

5.5.1.1 Eco-design policy

According to Kinsella and McCully (Kinsella and McCully, 1999), in ISO 14001, an environmental policy is defined as a "statement by the organization of its intentions and principles, in relation to overall environmental performance, which provides a framework for action and for the setting of environmental objectives and targets".

In this research, our environmental policy would be the same but tailored towards Eco-Design. Therefore, the policy must have the following elements:

- Be initiated and prepared through top management commitment to help to apply the WEEE and RoHS directives
- Incorporate a commitment to continual improvement and the prevention of pollution by paying specific attention to both materials and energy usage.
- Include a commitment to compliance with various laws and legislations.
- Provide a framework for fulfilling environmental objectives and targets
- Be documented, implemented, maintained, and communicated to all employees.
- Be available to the public where required.

The Eco-Design policy should not be a static and rigid document rather a dynamic and flexible. It is recommended that the policy should be reviewed annually or where necessary to reflect changing conditions and information within the organization as part of continual improvement. Any change in the policy should be carried out carefully so the policy does not lose credibility and/or become the flavour of the month!

Naturally, the policy would compete with other company policies, procedures, and memos, and may receive no more than a passing notice unless it is issued with a supporting awareness program. An environmental policy should be kept simple, presented with training, posted extensively including through e-mails, company website, and copies of the policies given to as many people as you can.

5.5.1.2 WEEE and RoHS implementation

The products might come within the scope of the WEEE regulation. Table 5.3 is a checklist for companies and organisations to use as they begin to apply the directives.

Table 5- 3 WEEE and RoHS directives checklist

1. Is the product or end application covered by the WEEE and RoHS Directives?

2. Does the product contain, or potentially contain the following materials: lead, mercury, hexavalent chromium, cadmium, PCBs, PBB, PBDE, radioactive substances, asbestos, and plastic parts more than 25 grams.

3. If the product can fall into the class of separately collected, does the product contain any of the following subjects, which will be removed from the product at end-of-life for separate treatment such as

- Fluids
- Polychlorinated biphenyls (PCB) containing capacitors.
- Mercury containing components, such as switches or backlighting lamps
- Batteries.
- Printed circuit boards of mobile phones.
- Other printed circuit boards greater than 10 square centimetres.
- Toner cartridges, liquid and pasty, as well as colour toner.
- Plastic containing brominates flame retardants.
- Asbestos waste.
- Cathode ray tubes.
- Chlorofluorocarbons (CFC), hydro chlorofluorocarbons (HCFC) or hydro fluorocarbons (HFC), hydrocarbons (HC).
- Gas discharge lamps
- Liquid crystal displays (together with their casing where appropriate) of a surface greater than 100 cm2 and all those back-lighted with gas discharge lamps.
- External electric cables
- Components containing refractory ceramic fibres as described in Commission Directive 97/69/EC of 5 December 1997
- Components containing radioactive substances.

4. What are the main concerns relating to end-of-life waste from the product eg

- Hazardous materials
- Recycled materials content
- Materials recyclability

5. What are the main design objectives/ attributes sought?

Design for: Longevity, source reduction, low toxicity, material or component recovery, separability of hazardous components or material and disassembly.

To apply WEEE directive you need to:

- Apply for registration with the WEEE Register Society Ltd.
- Pay the correct registration fee.
- The WEEE Register will issue you with a registration certificate and a unique five digit registration number.
- Display this registration number on Invoice, delivery dockets, credit notes etc…
- Automatically you will receive, by email your Username and Password from the WEEE Black box.
- Receive and complete WEEE Black box Historical Data Spreadsheet.
- Submit monthly data to WEEE Black box including weights and units of EEE products.

5.5.2 Planning (*The* plan *portion*)

The first part of the Plan-Do-Check-Act Eco-Design loop is the *plan* portion. In this work the plan portion consists of the following elements:

- [WEEE and RoHS Directives] Legal and other requirements
- Environmental aspects
- Objectives and targets
- Environmental management programme.

5.5.2.1 Environmental legislations, legal, and other requirements [WEEE and RoHS]

At this stage, plans have to be in place to identify all WEEE and RoHS requirement associated with all product life cycle stages. Well-documented procedures developed by the company or organization will most definitely help at this stage. Such procedure could be part of the company overall training pack for Eco-Design. The environmental department (which may be a group or an individual) in some companies has several means of identifying applicable rules and regulations, ranging from subscriptions to regulatory update services to existing well known and documented legal requirements.

Based on this research data analysis results in the field of Eco-Design information sources, section 4.6.1 titled Eco-Design external information sources, the project team should seek information from every available source without great discrimination. As it is important for companies to keep up and have a total knowledge of what is going on in the field of Eco-Design, and keeping up with the changes and the new legislations.

During the course of this work, the researcher identified a number of issues and problems could face companies when they attempt the implementation of different environmental legislations or directives. The list of such issues or concerns is presented in Table 4.46. The project team should have its own list of concerns and issues, which might slow or hinder the progress of the Eco-Design programs.

In section 4.10.1.1 of this work titled environmental legislation issues and problems. The researcher has come to a conclusion that most of the problems facing companies when it comes to environmental legislation are internal rather than external. These internal problems include lack of top management commitment, fear of extra cost and drop in profit, lack of confidence in own ability to comply with such legislations and regulations, lack of qualified staff, and resistance to change from traditional methods. This is exactly what happened when companies trying to apply WEEE and RoHS.

So, at this early stage of the WEEE and Eco-Design programme, the project team should start devising plans to tackle and resolve such issues. Top management commitment, training and education are vital to progress and success.

5.5.2.2 Environmental aspects

Every environmental aspect has an environmental impact. For example, the use of raw materials from non-renewable resources would most definitely result in depleting such materials and a good example of that is oil.

This part of the plan portion is very important, as Eco-Design is built on the evaluation of environmental aspects and reducing or eliminating their impacts. The Eco-Design project team should use logical and dependable methods and tools such as flowcharts and other tools listed in Table 4.28 of this work, in order to identify these aspects for any product design and associated production process.

After environmental aspects have been identified, the project team should determine the environmental impacts associated with each aspect. Life Cycle Assessment (LCA) provides the framework for analysing environmental impacts associated with a product. Other tools are listed in Table 4.28 in this work. The project team should have knowledge and understanding of these tools in order to use them where required.

As seen from the Table 4.28, using traditional tools for design is not wrong, but those tools were originally developed without environment concerns. So, in order for organization to design green products, tools such as MET matrix, Eco-design check list and the rest of the listed tools should be used to enhance the traditional tools for design or replace them all together, or by using WEEE directive as one of the most effective tool to design green products.

The main objective of looking at the environmental aspects at this early stage is to make the project team aware of the real challenges awaiting them as the Eco-Design journey unfolds, and to help the team to set objectives and targets.

5.5.2.3 Objectives and targets

"Environmental objective: overall goal, arising from the environmental policy that an organization sets itself to achieve, and which is quantified wherever practical."

"Environmental target: detailed performance requirement wherever practicable, applicable to the organization or parts thereof, that arise from the environmental objectives and that need to be set and met in order to achieve these objectives."

An ideal Eco-Design objective should include the following elements:

- Utilizing environmental directives guidelines from WEEE and RoHS.
- Involving all employees without exception in the company Eco-Design initiative.
- Involving all suppliers, sub-contractors, and customers without exception in the company Eco-Design initiative.
- Eco-improving the existing designs and related processes
- Eco-Designing all new products and related processes.

- Quantifying every bit of information where possible at the start and thereafter could serve as a success gauge for the programme.
- Getting ISO 14001 certification
- Utilizing all applicable ISO 14000 and other environmental directives guidelines.

However, setting Eco-Design programme targets to achieve the established objectives, which are implement WEEE directive, could take years rather than months. So, companies are advised to start with pilot schemes and progress to eventually include every design and process activity. Contact with other companies who applied WEEE directive, achieved ISO 14001 certification and have a well-proven Eco-Design record could be vital for success.

5.5.2.4 Eco-Design management system

The final phase the plan portion of the Eco-Design framework is to establish an Eco-Design management system. This phase of the Eco-Design implementation is the spine of the whole Eco-Design programme, and without a well-thought and effective management system, no real progress could be made especially in terms of integrating Eco-Design in the company's normal operation and strategy and the whole programme is doomed to failure.

In order to implement this part of the *Plan* portion, the cross departments' team or teams responsible for the implementation of the Eco-Design project should take into account the following items and prepare well for them.

1. International certification
2. planning to achieve any certification or validation related to Eco-design, WEEE
3. Ranked reasons for implement management standards

Section 4.9 of this work gives a detailed discussion about the survey analysis results of each of the above items. World-class companies in the field of Eco-Design would implement and take care of every single item in the above list.

As shown in Table 4.46, 45% of respondents answered yes to question 30, which is an encouraging result, and it highlights a great interest in Eco-design and WEEE among companies.

As shown in Table 4.47, competitive advantages ranked as the highest reasons for implementing management standards, then facilitating compliance with WEEE and RoHS, and Improve eco-design performance takes the second place for implementing management standards.

Furthermore, the management system must identify, where possible, how each objective and target will be met, including assigned time frames and personnel. Organisations should establish mechanisms for the Eco-Design objectives and targets to be achieved. Responsibility and resources must be designated, with time frames set for meeting the objectives and targets within an Eco-Design management system.

When it comes to cost, organizations could use the annual budgeting process as a means to determine funding needs for the Eco-Design programme. At this time, specific programs are identified that will support the objectives and targets for the new fiscal year. In addition, the company needs to provide resources to the departments and divisions so they are able to meet the demands of objectives and targets established by the Eco-Design programme, thus facilitating implementation of WEEE as an integral part of the business's activities and strategy.

5.5.2.5 Discussions on Planning (*The* plan *portion*)

As presented above, the four main sections of the *plan* portion should be implemented, and their implementation could take place simultaneously where applicable and not necessarily in the presented order.

At the end of this stage, according to the author and to the *plan* portion implementation, the project team should be able to positively answer the following questions:

- Have you identified the environmental aspects of the project?
- Has WEEE and RoHS directives been considered for implementation?
- Have you identified all the requirements to apply the directives?

- Have you checked all the scope and exceptions for the WEEE and RoHS?
- Do you have the tools required to identify environmental aspects?
- Have you identified the environmental impacts associated with each environmental aspect?
- Have you identified the regulated aspects, how are they regulated?
- Have you identified not directly regulated aspects and how can they be improved?
- Do you know how the legal and other requirements about WEEE and RoHS directives associated with the project could be identified, obtained, and fulfilled?
- Have you identified the challenges and obstacles facing the Eco-Design team to implement the WEEE and RoHS directives at this stage and may be in the future, and how they can overcome them?
- Have you decided on the objectives and targets of the project?
- Have you decided on the scope of this project?
- Has a pilot scheme been selected as a starter for the Eco-Design programme?
- Do you know how to check, and act on the project?
- Have you decided on how much should be done before checking the results?
- Have you decided on how much should be checked before acting on conclusions? And how much should be acted upon before planning the next cycle?
- Have you decided on who should be involved in the project?
- Have you identified what should be measured? How? When?
- Have you sought help and advice from other successful companies in the field of WEEE, RoHS and Eco-Design?
- Have the Eco-Design starter requirements from management been identified and acted upon?

- Have all Eco-Design internal and external information sources been identified and used?
- Have all relevant local and international environmental certification been identified?
- Has ISO 14001 been considered for implementation?
- Has an integrated management system been put in place where relevant?
- Have plans been drawn out to link industrial ecology to business strategy, including identifying the required tools to achieve that?
- Have time, money, personnel, and authority for the project been allocated?

Companies could add or modify the above list of questions where necessary based on the unique or specific nature of their operation, but as a prerequisite to progressing to the *Do* portion, the above questions should be ideally answered positively and in full where both applicable and necessary. The above questions could be viewed as an assessment tool or a checklist for this part of the implementation. A Yes answer is required for all of the above questions where applicable and necessary, and a No answer should prompt more work on the plan portion of this implementation.

5.5.3 Implementation and operation (*The* Do *portion*)

The implementation and operation is the *Do* portion of the Plan-Do-Check-Act improvement cycle. When planning is completed, the project team should be ready by now for the implementation work. The implementation work in this research includes eight elements as follows:

1. Structure and responsibility
2. Training, awareness and competence to apply the directives
3. Design considerations :Environmental concerns, system design, material sourcing, manufacturing and distribution, use and end-of-life
4. Eco-Design tools, rules, principles, and considerations for taking WEEE into account
5. Eco-Design management of natural resources (materials and energy)

Apart from structure and responsibility, which should be carried out at the beginning of this phase, there is no priority of implementation among the rest of the elements. They could be carried out simultaneously if required. It is down to the individual organisation's needs and requirements.

5.5.3.1 Structure and responsibility

This part of the implementation comes as a continuation to section 5.5.2.4 titled Eco-Design management system of this work. This element of the Eco-Design project should be implemented clearly and precisely to avoid lack of responsibility, not my problem attitude, and to strengthen the ownership of the project from different individuals or teams, especially when problems arise and need solutions. Therefore, the organisation must do the following:

- Define Eco-Design project management responsibility and authority.
- Provide resources for the WEEE directive and Eco-Design project.
- Appoint one or more people to be responsible for this project with clear duties and authorities.

Clearly defined roles and responsibilities for implementing the WEEE directive come from a management structure that should be established early in the implementation process of Eco-design to provide people with the authority to implement the Eco-Design project. Senior managers need to send a clear message to employees that the Eco-Design project has their support.

When it comes to structure and getting organized, the following tips are helpful:

- Create an organisation chart.
- Let people know the goals of your team
- Build team pride by setting and implementing goals.
- Training, awareness and competence to apply the directives

5.5.3.2 Training, awareness and competence to apply the directive

Many organisations have environmental training programs in place to cover the regulatory requirements of their businesses, such as hazardous waste handling, asbestos issues, etc. However, Eco-Design programme requires a different type of training. The Eco-Design training package for involved employees should be structured and focused on Eco-Design issues, with specific timeframe and or as required. The training must cover the WEEE and RoHS Directives scope, exceptions, penalty etc.

Training manuals and sessions should be tailor-made to suit different types of employees, for instance training design engineers is different from training procurement personnel. Training should be designed and carried out deliberately not casually.

Evaluate the effectiveness of Eco-Design training by asking for feedback from employees. Employees should also be interviewed occasionally or when required to sustain their level of awareness of the Eco-Design programme and the WEEE directive.

The research analysis result has shown that companies starting an Eco-Design project are lacking proper training programmes and that would most likely hinder and delay their progress.

5.5.3.3 Design consideration to apply WEEE and RoHS: Environmental concerns, system design, material sourcing, manufacturing and distribution, use and end-of-life

The researcher in this work is treating the environment as a customer in the conventional sense. The reasoning behind that is if companies look after the environment as they look after their own customers then the whole perception of the environmental related issues would improve. The most popular items, which concerns environmentally oriented customers, are listed in section 4.7titled design considerations which should be monitored to apply the WEEE and RoHS directives. In our research we divide the design consideration to six parts as follows

- Environmental concerns
- System design
- Material sourcing

- Manufacturing and distribution
- Use
- End-of-life

The list contains the following items:

- Regulatory requirements WEEE/RoHS
- Customer requirement
- Environmental load
- Reduced complexity of enclosures and assemblies
- Fewer parts
- Multifunctional parts
- Using common parts in different designs
- Multifunctional products
- Is longevity considered
- Is source reduction considered
- Recycled materials specified for product materials and packing
- Hazard materials avoided or minimized
- Scarce resources avoided or minimized
- Energy conservation in manufacturing and distribution
- Waste minimisation in manufacture
- Minimise the air and water pollution
- Minimise the water and material use
- Minimum power consumption in use

- Minimum packaging
- Minimum consumables use
- Minimum waste consumables in use
- Serviceability, longevity and durability
- Design for non-destructive removal
- Design for speedy diagnosis and refurbishment
- Design for close loop manufacture
- Design for secondary applications
- Is there market for the removed material
- Is there a separation and recycling technology and infrastructure
- Is there any other requirement for material separation RoHS
- Material combinations compatible for recycling
- Use of recyclable materials
- Grouping hazardous or non recyclable components
- Use of standard screw heads
- Use of detachable leads and push in plugs
- Is the component assembly designed to ease of assembly
- Simple component mechanism and orientation
- Provision of grasping parts
- Use of screws in preference to rivets
- Snap fit for spring clips in preference to threaded fasteners

- Common fasteners

The survey analysis results of the above list as presented in section 4.7 Design considerations, has shown many interesting points, which companies should take into account when embarking on their Eco-Design journey and implement the WEEE directive. Respondents in our survey rated themselves highly in the following fields:

- Customer requirement
- Environmental load
- Using common parts in different designs
- Use of standard screw heads

On the other hand, respondents in our survey rated their products rather moderately in most of the fields. The above results show that companies are already doing well in some fields even without being involved directly in Eco-Design programmes or have just started the WEEE directive scheme. However, Eco-Design committed companies have to work hard to improve and score highly in all of the above points where applicable. Once again, the researcher would like to stress the importance of reducing the amount of energy used in any product from its raw materials extraction to its end-of-life options. Energy is involved directly or indirectly in every item of the above list. By using the above list the implementation of WEEE directive will be a lot easier.

5.5.3.4 Eco-Design tools, rules, principles, and considerations for taking WEEE into account

This part presents different types of tools and important considerations, which can be used at different stages of the Eco-Design journey of implementation. The Eco-Design tools and considerations are divided into five sections based on relevancy as shown in section 4.5 of this work.

1. Tools for environmental analysis and instruction
2. Tools for creativity techniques
3. Tools for setting priorities and decision-making

4. Tools for cost accounting
5. Eco-Design considerations [Design for X family (DFX)]

The survey's analysis results of the above tools and considerations have revealed the following:

- Respondents still using traditional tools for both designing products and calculating costs and yet to utilize Eco-Design oriented tools.
- Eighty percent of problems or factors facing companies in using Eco-Design tools and considerations are internal rather than external.
- Lack of knowledge in the field of Eco-Design.

The above tools and considerations are the medicine to relief the pain suffered by many companies in their quest of Eco-Design. Traditional tools are neither sufficient nor equipped to tackle Eco-Design issues and requirements. Combining traditional methods with Eco-Design methods and tools could be the answer to many problems faced by companies. Therefore, companies are urged to use the above tools where applicable and not be shy from learning and experimenting with them.

5.5.3.5 Eco-Design rules and principles for implementation

This section is divided into two parts. The first part is Eco-Design rules for implementation, and the second part is Eco-Design principles for implementation. The two parts are inter-related and complement each other.

Eco-Design rules for implementation:

The eight golden Eco-Design rules for implementation are a very effective tool for a successful deployment of Eco-Design. These rules can be applied and tested in any manufacturing situation, or in other words they are the rule of thumb for any Eco-Design programme. The following are the eight golden rules of Eco-Design implementation.

1. Ensuring any assessment of a product's environmental compatibility must include its whole life cycle. The analysis should be from cradle to grave.

2. Ensuring the intensity of processes, products and services has to be reduced drastically.
3. Ensuring the material intensity of processes, products and services has to be reduced by a factor of 10 and the productivity of resources increased accordingly.
4. Ensuring the energy intensity of processes, products and services has to be reduced by a factor 10 and productivity of sources increased.
5. Ensuring the land use per service unit has to be minimised and the productivity of resources increased.
6. Ensuring the emission of hazardous substances has to be eliminated.
7. Ensuring the sustainable use of renewable resources has to be maximised.
8. Ensuring to benchmark all of the above against the best similar eco-products available where possible.

Eco-Design principles for implementation

This part covers the Eco-Design principles, which should be deployed where applicable during the whole life cycle of any product. The Eco-Design principles for implementation are listed as follows:

- Use all materials optimally
- Minimize pollution during extraction
- Select material that minimize pollution during processing
- Select material that minimize pollution during deployment
- Select materials that minimize pollution during recycling
- Select materials that minimize pollution during disposal
- Select materials that minimize pollution during transport
- Use all energy resources optimally
- Ensure the product has minimal adverse effects on the environment during manufacture

- Ensure the product has minimal adverse effects on the environment during deployment
- Ensure the product has minimal adverse effects on the environment during recycling
- Ensure the product has minimal adverse effects on the environment during disposal
- Evaluate product disposal methods
- Ensure the product service life is appropriate
- Ensure to shop locally if possible
- Ensure implementing environmentally friendly logistics

Considerations for taking WEEE into account

In order to prepare to join the WEEE directive, the following list shows the important points to be checked before implement the directive:

- Products covered by WEEE and RoHS
- Electrical and Electronic product Categories
- Products contain hazard substances RoHS
- Products contain material, which required to be removed at end-of-life based on WEEE directive
- provide the re-use and treatment information
- Actions from the producers to meet the WEEE directive

Based on the results there are a strong respond to the WEEE and RoHS directive as show in table 4.9, Tables 4.14, 4.15 and 4.16, but based on the result tables 4.17, 4.18 and 4.19 treatment should be done and in order to prepare to join the WEEE directive table 4.20 shows the results.

The general trend and perceptions among respondents is that a lot could be done to improve the preparation to implement the WEEE directive. After all, legislations are set and imposed by authorities, and then concerned organisation' compliance is tested, and enforced by the same authorities.

So, based on the analysis results, it is important to encourage the eco-design in order to make it easier to reuse, recycle and recover the waste from the electrical and electronic equipments.

5.5.3.6 Eco-design management of natural resources (material and energy)

This part of the implementation process is a collection of principles for both materials and energy management throughout different stages of products' life. Companies would benefit from applying these principles as part of their Eco-Design implementation programme to help to apply WEEE directive. The principles are as follows:

- Principles of materials management
- Principles of materials recycling [Design for recycling (DFR)]
- Principles of materials and/or components recovery [Design for disassembly (DFD)]
- Principles of extending the service life of products
- Principles of energy utilization

Principles of materials management

The principles of materials management cover the entire life of any product's materials from cradle to grave. Eco-Design oriented companies normally apply these principles to their products design and manufacture. The following is a list of these principles.

- Minimize the amount of materials in each part
- Lengthen the service life
- Specify recycled materials whenever possible
- Specify energy efficient materials in manufacture
- Specify materials that pollute minimally during their extraction

- Specify materials that pollute minimally during their manufacture
- Specify materials that pollute minimally during their use
- Specify materials that pollute minimally during their disposal
- Specify readily available materials that do not deplete declining natural resources
- Specify materials that are unlikely to be affected by new legislation that will constrain their deployment
- Specify materials that are unlikely to be affected by new legislation that will constrain their manufacture
- Specify materials that are unlikely to be affected by new legislation that will constrain their disposal

The responses highlighted that, when shopping for materials, respondents in our survey are not paying enough attention to sourcing and selecting materials that do not contribute to declining natural resources, and pollute minimally during extraction, discussed in section 4.7.3, 4.7.4, 4.7.5 and 4.7.6.

Companies could start by adopting a basic checklist for selecting materials to give them guidance and acts as a rule of thumb. Table 7.3 presents a checklist for environmentally selecting materials (Fuad-Luke, 2002).

Table 5- 4 Checklist for environmentally selecting materials

Material attribute	Low environmental impact	High environmental impact
Resource availability	Renewable and/or abundant	Non-renewable and/or rare
Distance to source (the closer the source the less the transport energy consumed) Km	Near	Far
Embodied energy (the total energy embodied within the material from extraction to finished product) MJ per Kg	Low	High
Recycled fraction (the proportion of recycled content) per cent	High	Low
Production of emissions (to air, water and/or land)	Zero/Low	High
Production of waste	Zero/Low	High
Production of toxins or hazardous substances	Zero/Low	High
Recyclability/reusability	High	Low
End-of-life waste	Zero/Low	High
Cyclicity (the ease with which the material can be recycled	High	Low

Companies could add more items to the list as necessary, and better make their own tailor-made checklist.

Principles of materials recycling [Design for recycling (DFR)]

- Materials' recycling is an important part of materials management as it has a direct and significant impact on natural resources, especially non-renewable resources such as fossil materials, iron, copper, aluminium, and so on. The following are the principles of materials recycling.
- Ensure long product life with the minimized use of raw materials (source reduction)
- Ensure minimizing the number of different materials in a product
- Ensure selecting easily recycled materials
- Ensure the ease of product disassembly

- Ensure facilitating material identification
- Ensure the ease of separation of different materials
- Ensure using fewer components within a given product in an engineered system
- Ensure an increased awareness of life cycle balances and reprocessing expenses
- Ensure to increase number of parts or subsystems that are easily disassembled and reused without refurbishing
- Ensure using more adaptable materials for multiple product applications
- Ensure designing for fewer 'secondary operations' reducing the amount of scrap and simplifying the recovery process
- Ensure designing for disassembly (DFD)
- Reducing labelling on plastics.
- Reducing hazardous materials such as in cathode ray tubes (CRT) and batteries
- Making hazardous materials easy to access for removal
- Selecting recyclable packaging
- Maximisation of profit (benefits-costs) over a product's life span
- Maximisation of the number of parts reused
- Minimisation of the amount (weight) of landfill waste of electrical and electronic equipments

The above is rather a comprehensive list. However, companies could add to it or modify it where applicable, and end up with it is own list of principles. The data analysis results in our survey, in sections 4.7.2, 4.7.3 and 4.8 have shown the following important points:

- Companies are still not taking ownership, when the product comes to its end of useful life due to not deploying at the design stages the factors, which would help when applying the WEEE directive, recycling and eco-disposing, such as Design for Disassembly (DFD).

- Companies not actively selecting materials that pollute minimally during both extraction, disposal, and not from depleted resources.

Principles of materials and/or components recovery [Design for disassembly (DFD)]

The previous section DFR is highly dependent on this section DFD. The following principles of materials and/or component recovery are highly beneficial when deployed at the earliest possible chance during the design phase.

- Information about the design available on Manual, CD-ROM or On line
- complexity of Reduced enclosures and assemblies
- parts Fewer
- Multifunctional parts
- Using common parts in different designs
- Material combinations compatible for recycling
- Use of recyclable materials
- Grouping hazardous or non recyclable components
- Use of standard screw heads
- Use of detachable leads and push in plugs
- Is the component assembly designed to ease of assembly
- Simple component mechanism and orientation
- Provision of grasping parts
- Use of screws in preference to rivets
- Snap fit for spring clips in preference to threaded fasteners
- Common fasteners

The result of our survey presented in section 4.7.2, 2.7.6 of this work, has shown that companies at early stages of Eco-Design are generally not applying these principles to a satisfactory level. Companies are not fully applying important aspects of Eco-Design such as incorporating a material identification scheme on parts to simplify their identification and separation. This would result in difficulty in recovering the correct type of materials and would result in a high recovery cost, which could lead to scrapping the whole recovery plan for such products. On a good point, companies are making good progress in terms of reducing the number of assembly operations and simplifying and standardizing the fits.

According to the result in Tables 4.41, 4.42, our respondents are not fully incorporating the end-of-life assessment into their designs.

Companies are strongly advised to have a system of design that would make sure of incorporating DFD and end–of-life considerations as a deliberate part of the design process, not the other way round, and this will make applying the WEEE directive easier.

5.5.4 Checking and corrective action (The *Check* portion)

By now, the interested company should have established a significant part of the Eco-Design programme by fulfilling the pre-requisite requirements to apply the WEEE directive, decided and established an environmental Eco-Design policy as explained in section 5.5.1 of this work, planned the Eco-Design properly and how to implement the WEEE directive as explained in section 5.5.2 of this work, and then successfully deployed the implementation part as explained in section 5.5.3 of this work.

At this stage, companies should have produced or at least designed an Eco-Design based product(s), and paved the way to implement the WEEE directive into the company's anatomy. However, the journey of the Eco-Design has not finished, on the contrary it has just started. In order to keep the momentum going, this portion of the implementation is very important, as it is the gauge, which will give the company the chance to test, check, correct and improve its process and product. The checking and corrective action allows companies to measure how well their Eco-Design programme is working. After all, Eco-Design is about continuous improvement. This portion of the improvement loop would police the whole programme and would pave the way to the next portion of the implementation.

The ***Check*** portion includes the following parts:

- Measure eco-design and WEEE performance
- Establish an Eco-design audit programme to help to take into account WEEE directive

5.5.4.1 Measure Eco-design and WEEE performance

Companies should first of all, decide on the parameters they want to measure. These parameters could be the amount of waste, energy consumption, amount of materials uses, etc. These parameters should be quantified and measured before embarking on any Eco-Design activities. This information would be required later for monitoring and measuring any progress made. Methods to record these data should be established in order to track performance, and check conformance with environmental objectives and targets. Many statistical tools and charts are readily available to help achieve this goal such as SPC (Statistical Process Control), and tools from section 4.5.1 such as LCA, MIPS, ABC analysis, etc. as well as existing methods of measuring which are already being used by companies.

To be consistent and reliable, all of monitoring and measuring procedures should be documented in order to regularly monitor and measure the key characteristics of your products' design that have significant environmental impact. The key characteristics should be decided by the company and depend on the nature of the products. When applying the WEEE directive these characteristics could be the most important ones:

- Rate of reuse
- Rate of recycle
- Rate of recovery
- The amount of CO2 emission
- Energy consumption

There should be procedures used to calibrate monitoring equipments and keep calibration records. A documented procedure for periodically evaluating compliance with environmental regulations should be implemented where required.

The most popular Eco-Design attributes, which can be measured, are as follows:

- Low energy use
- Low materials use
- Low water use
- No hazardous materials
- Easy assembly
- Easy disassembly
- Few components
- All renewable materials
- All recycled materials
- All recyclable materials
- All same materials
- Low process emissions to air
- Low process waste-liquid
- Low process waste-solid
- Low health and safety risk
- Reusable packaging
- All recyclable packaging
- No packaging
- Low transport cost

Individual companies could modify the above list where applicable and then decide on a scale in order to be able to quantify and measure the above attributes. Having measured the above factors, companies should then start remedying any shortfalls in order to achieve the required goals and objectives. The tools presented in section 4.5.1 could be utilised to help in this quest. Continuous improvement is a never-ending cycle.

In order to effectively manage an Eco-Design programme, maintaining and using environmental records are paramount. Records must be readily available, maintained and protected from damage, deterioration, or loss. Companies will need to identify the environmental records that are needed to ensure the availability of a useful and up to date environmental database, which can be both used and effective during implement the WEEE directive.

5.5.4.2 Establish an Eco-design audit programme to help to take into account WEEE directive

In order to keep the Eco-Design programme on track and moving forward, companies have to establish an audit programme in order to assess the progress made in relation to achieving objectives and targets set earlier in the Eco-Design project. The audit programme should have a set of measurable factors to be tested and checked on regular basis. The factors to be measured and audited could be selected based on company's own set of Eco-Design objectives which should be achieved the WEEE directive requirements, increasing the use of recycle materials by x number, reducing energy consumption by x number and so on.

The first internal audit should be a baseline audit of your current system to identify gaps between your Eco-Design objectives which the important one of them is the implementation of WEEE directive and potential Eco-Design product(s). Your implementation will then be focused on closing these gaps. A gap analysis is a valuable tool to be used at this stage.

The purpose of this element of the *Check* part is to ensure that continuous oversight and management of the Eco-Design programme is achieved and a mechanism is in place that allows corrections to be made. While it is important to have a good corrective action process in place, organizations are expected to be more proactive than reactive. The preventive action side of the system should be equally as strong as or stronger than the corrective action side.

All corrective actions should be recorded and maintained as a part of the Eco-Design programme records within the wider EMS records.

5.5.5 Eco-Design implementation's results management Review (The *Act* portion)

The final part of the Plan-Do-Check-Act improvement loop is the *Act* portion, which is referred to in this work as the Eco-Design implementation's results management review. At this stage of the Eco-Design implementation, the company should have had product(s) designed using Eco-Design principles and guidelines as outlined in the earlier stages of this cycle. Also, at this stage, it's preferred that the product(s) been looked at as a prototype(s) rather than final product(s) ready to be marketed. The rationale behind that is managing positively risk, time and cost. It's a lot cheaper, quicker and less risky to start with a pilot product rather than applying the implementation to a whole range of products. So, you could allow full and comprehensive reviews of the product and associated processes for any changes as a part of continuous improvement, and/or act on the undesirable results from the *Check* part of the programme.

The company should act on conclusions and results, both desired and not desired. If desired results were achieved and objectives were met, then the *Do* portion was a process change for better and should be standardized and continually refined as part of the company's wide continuous improvement programme. However, if undesirable results were obtained and objectives were not met, then the *Act* portion of this implementation should be activated in full.

As stated in Table 5.1 of this work, the act portion utilizes the conclusions and results from the *Check* portion. The following questions should then be answered and acted upon their answers:

- Should we continue working on this process?
- Do we need to collect more data?
- Do we need to get more suggestions?
- Should we seek experts' help?

- Should we refine the process?
- Should we drastically change the process?
- Should we abandon the process and start from the beginning?
- Should we run through the cycle again, possibly under different environmental conditions and/or factors?

The Eco-Design implementation's results management review process must be documented. The Eco-Design management team must define how often this is done and what is reviewed and acted upon. It is expected that the following items will, as a minimum, be reviewed:

- The Eco-Design policy and the WEEE directive.
- The results of Eco-Design audits and findings.
- The effectiveness of the corrective and preventive action system
- Performance against established objectives and targets

The following steps will help to develop and use the Eco-Design implementation's results management review process (Kinsella and McCully, 1999):

1. Document the Eco-design and WEEE implementation's results management review process
2. Implement the results management review process
3. Use the results to drive Eco-design and WEEE improvement
4. Review: The Eco-design policy and WEEE and RoHS directives, the findings, the audits, the effectiveness of the corrective and preventive action system, Performance against established objectives and targets

5.5.5.1 Document the Eco-design and WEEE implementation's results management review process

Design the Eco-Design implementation's results management review process. The process could include:

- People involved in Eco-Design and WEEE directive implementation's results action process.
- Items to be covered in Eco-Design implementation's results action process meetings.
- Records to be kept and the person responsible for these records.

The process can be documented in a procedure that will guide the Eco-Design management team.

5.5.5.2 Implement the results management review process

The Eco-Design implementation's results management review process can be implemented in progressive stages. For instance, during the initial Eco-Design development, the reviews of the Eco-Design implementation's results action process can be performed more frequently and be used to drive implementation. Progress reports can be presented along with guidance for resources if needed. After the full Eco-Design programme is in operation, the frequency of reviews can be readjusted based on needs and requirements.

5.5.5.3 Use the results to drive eco-design and WEEE directive improvement

The Eco-Design implementation's results management review process can be used to make changes and improvements in the Eco-Design programme. New objectives and targets and new methods of operation and processes can be drawn from the results and analysed during management reviews

5.5.5.4 Review

Examine other review activities to determine whether the Eco-Design implementation's results management review process can be modelled after a successful process already in existence. Most organizations struggle with this aspect of either an Eco-Design programme or EMS because it is difficult to step back and examine the performance of the entire system. Because management reviews are a critical function of both Eco-Design programme and EMS, alternatively, companies may want to conduct these separately from other meetings. Drawing boundaries between different programmes could be both beneficial and effective.

CHAPTER 6 CONCLUSION AND RECOMMENDATION

The research presented in the preceding chapters presents a comprehensive literature review, an exploratory study of the state of Eco-Design activities, the WEEE directive implementation and performance among a sample of companies who are interested in applying the directives and Eco-Design in the United Kingdom. The aim of this research is to provide businesses with a framework, which could help in designing successful environmentally friendly products and implement the WEEE directive by integrating Eco-Design activities to a company's operation and strategy. The framework aimed at all electrical and electronic equipments companies and businesses involved in design and manufacture.

This Chapter includes the following parts:

- Conclusions on qualitative, quantitative work and PDCA framework.
- Aim and objectives revisited.
- Recommendations for further research.

6.1 Conclusions on qualitative, quantitative work and PDCA framework

This part is conveniently divided into three sections. The first section presents the conclusions on the qualitative work of this thesis, which includes the literature review. The second section presents the conclusions on the quantitative work of this thesis, which includes the questionnaire survey data analysis results. The third section presents the conclusion on the proposed PDCA for Eco-Design framework.

The following conclusions on qualitative work can be made:

- There are many different approaches on how to develop sustainable products. Eco-Design is one of these approaches, and its principles should be both sustainable and successful.
- Carrying out a research in Eco-Design is a challenge due to a number of reasons; the most prominent one is that Eco-Design is still a relatively new subject.
- Companies will no longer be able to treat and look at environmental issues as a mere cost and burden, which should be avoided and not taken care of. A stage has been reached where dealing with environmental issues is becoming a prerequisite to design and manufacture of products as WEEE directive.
- The amount of legislation coupled with consumer awareness and competition is surely paving the way towards sustainable developments.
- Treating the environment as a customer is a step on the right path to the journey of sustainable design. Environmental attributes should be dealt with at the design stage and through the whole life cycle of products.
- Different authors are using different environmental terms to describe the same subject, which could create confusion especially among people who are not familiar with the world of academia and research. For instance, DFE, Eco-Design, sustainable design, green design, environmentally friendly design and so on and so forth are different terms describing the same thing even though some authors would try to differentiate between them in a philosophical way.

- There are many terms and definitions of Eco-Design, but the bottom line definition of Eco-Design could be “any design process and its related activities, which leads to conserving and using materials and energy throughout the product life cycle”.
- The problem with LCA is limited usage in presenting it as a sole tool, which would somehow produce green products. LCA would work better if it is utilised as a part of other similar and complementary tools within an Eco-Design framework, and not singled out as the one and only tool.
- There are not many publications about the impediments of Eco-Design but rather about the drivers for Eco-Design. That is fine, but without knowing the real barriers of Eco-Design, it would be difficult to overcome them, and the struggle would carry on. More research should be done to look into the negatives and find ways to turn them into positives. Not forgetting for companies who are not implementing or resisting Eco-Design, the negatives and impediments for them could be seen as reality, and the drivers are as mere promises.
- The Eco-Design process could vary from one product to another, but the main objective remains the same. All principles of Eco-Design should be observed and fulfilled where humanely possible.
- Environmental management systems (EMS) and its related ISO 14000 family of standards could be a stepping-stone in the quest of Eco-Design.
- In the literature, the emphasis on DFD and DFR as it is very important when applying the WEEE directive, but the author believes that all DFXs are important, and should be given the same emphasis because for instance if a product designed with DFS at the outset could last longer and save in both materials and energy.
- Companies have to treat Eco-Design and the environment as an important part of its business strategy not just a project here and there.
- Environmental voice of customers and its associated engineering metrics could be used as a rule of thumb to achieve environmentally friendly products.

- Not many tools have been developed specifically for Eco-Design and that could be due to the relative new nature of the subject, which results in few innovative tools.
- Not many authors have published comprehensive research about Eco-Design tools. This could contribute to the lack of popularity of available tools, simply because companies and interested parties do not know about them. The solution to that could be by publishing or establishing an up-to-date database, which contains all available tools and how to use them.
- Companies are approaching the subject of Eco-Design as an isolated project, which if it fails it could be easily blamed and ditched. The author believes that Eco-Design should be embedded in the company's operation and strategy and not be dealt with as a separate pilot scheme, which could fail, and be forgotten.
- The rather enormous activities and information of Eco-Design implementation should be carried out within a well designed and thought out framework; otherwise companies will not be implementing but rather trouble shooting.
- The objective of nearly all the existing Eco-Design frameworks is to integrate environmental aspects into product design which could be the WEEE directive. In most cases, they are developed for specific piloted product(s) and not generic in nature. Furthermore, these frameworks are mainly developed for the product designer(s) to implement them, and in many cases the product designer(s) are behind the development of these frameworks. Furthermore, these frameworks ignore the valuable inputs that could be provided by different departments such as marketing, accounting, production and manufacturing. Product designer(s) as much as they are genius they do not really know or have solutions for everything.
- Existing frameworks are merely attempts to try to produce pilots of environmentally friendly products without involving the company as a whole in the project; consequently the chances of success are very limited and nearly 90% of all eco-technically good products do not make it to the market. So, these frameworks on their own do not provide a realistic opportunity and almost all of them will start and finish as pilot schemes.

- Using Eco-Design frameworks only, without top management involvement and commitment in addition to other important Eco-Design activities including provision of Eco-Design education and training, is a recipe for failure and a dead end road for Eco-Design initiatives
- The success of EMS (Environmental Management System) implementation and consequent ISO14001 accreditation was only possible due to establishing a framework for EMS implementation and management, which was integrated into the business's normal operation and strategy.
- The frameworks attempting to integrate Eco-Design activities into the business are a step in the right direction towards an Eco-Design programme, which is integrated in the business's operation and strategy.
- These frameworks demonstrate the business seriousness about the Eco-Design programme and have some of the required ingredients, which will lead to its successful implementation. For instance, they involve Eco-Design tools, WEEE directive requirements, communication, whole life thinking, business strategy, sales and marketing, top management commitment, etc. However, other very important ingredients are still missing such as considering all aspects of Eco-Design activities including proper consolidation of top management commitment, Eco-Design policy, education and training, tools for different stages in the Eco-Design programme, proper planning including setting up an Eco-Design management team, different requirement for the actual implementation, continuous improvement provisions.
- What is required is a detailed and comprehensive framework for Eco-Design, which includes all of the above ingredients, which could guarantee both successful implementation of WEEE helped and supported by integrating the Eco-Design programme into the business's operation and strategy.
- The Eco-Design framework and the associated implementation plan developed as part of this study came as a direct result of the literature review, which to identifying many gaps and opportunities for further research, and the findings of the analysis results carried out as part of this work empirical research. The PDCA Eco-Design framework provides businesses and companies with a rather comprehensive plan which facilitates the implementation of WEEE and

integration of Eco-Design activities into business's normal operation and strategy coupled with a continuous improvement cycle. The framework should help companies to pass the stage of the pilot scheme and make Eco-Design the defaulted way of designing both products and processes. The success of the implementation relies on top management commitment and involvement starting with an Eco-Design policy initiated by management and all stakeholders. It is suggested that top management should sign the policy and it should be publicised where possible to all interested parties.

The following conclusions on quantitative work can be made:

- Respondents are taking into account to a very great extent to apply the WEEE and RoHS directive and preparing to achieve good results.
- Respondents are taking into account to moderate extent only the parts of the product life when the product reaches the end-user such as a product's deployment and disposal and energy consumption. At the end of the product life cycle and when the burden of disposing it falls on the society, which is represented by the local council or authority, respondents are not effectively taking into account their products recycling, disposal and so on.
- The issues and problems facing respondents when it comes to environmental legislations as WEEE and RoHS directives are fear of extra cost and/or drop in profit, their ability to comply with such regulations, lack of proper guidance in this field by insufficient environmental regulations, lack of qualified staff, and resistant to change from traditional methods.
- Legislations play a big part in choosing materials and companies are looking ahead by choosing materials, which will not be negatively affected by future legislations.
- Respondents do major on issues to do with restricting laws and regulations and at the same are subjected to tests and audits. Our respondents conform to a great extent to the elimination of hazardous emission.
- Optimum use of both materials and energy are the pillars of Eco-Design, and everything the company does to implement environmentally friendly design and process would ultimately be linked directly or indirectly to materials

and/or energy. Naturally, the voice of customers when it comes to the environment would be related to both materials and energy.

- In the motivators' part, legislations were given thumbs up from respondents as number one motivator for their Eco-Design programme followed by publicity and image. Consumer pressure came as a middle ranking rate.
- In the barriers' part, readiness of companies to invest money and capital into Eco-Design programmes still questionable, and cynical attitudes about the benefits still linger among different management levels.
- Respondents are not making a good use of different sources of information when it comes to Eco-Design, and the old way of gathering information still prevails
- All of our respondents have at least achieved one of the legal standards ISO 9000, ISO4000 and ISO14001 so they have a good knowledge and experience in fulfilling the requirements of such schemes. Furthermore, overall respondents considered implementing or gaining a management standard such as ISO 14001 would be very helpful when it comes to competition and national and international trade. In addition it would help in their quest for improving their Eco-Design schemes and comply with Eco-Design relevant legislation.
- Most of our respondents have knowledge of Integrated Management Systems (IMS), but that knowledge is only limited, and the way that their companies run their management affairs would be only have of a limited help when it comes to implementing IMS for Eco-Design. Overall, our respondents are making a good use of some of the available techniques for linking industrial ecology and business strategy.
- Whether there is sufficient help from authorities or not, the general trend and perceptions among respondents is that a lot could be done to improve the role of authorities. After all, legislations are set and imposed by authorities, and then concerned organisations' compliance is tested, and enforced by the same authorities

- On the whole, respondents are still do major on using traditional tools when it comes to designing products or calculating their costs, and yet to utilize Eco-Design tools.
- 80% of problems or factors facing respondents when it comes to Eco-Design are internal rather than external. Senior management, education and training are the champions of these factors. Shying away from utilizing different tools from the traditional ones is hindering the proper development of environmentally friendly products. For instance, when it comes to design creativity, respondents still use the classical brainstorming only. DFR, DFS, DFT and DFUG are still not considered properly and sometimes not at all when it comes to design.
- The researcher in this part feels that there could be two possibilities behind respondents answering not applicable to almost all of the well-proven tools in the field of Eco-Design. The first possibility, respondents do know about these tools, but they consider them to be not applicable, or the second reason could be, they do not know about them but shied away from answering as (do not know).
- Less energy consumption is still not taken into account as it should be, as manufacturers are still designing products that use more energy during both manufacture and usage. In comparison to their predecessors just look at vacuum cleaners getting smaller in size and bigger in power consumption.
- Respondents are still not paying serious attention to their products' energy consumption, and are only paying a moderate attention to energy when it comes to engineering metrics. The reason behind that could be either companies believe that their energy consumption is optimum and cannot be improved, and/or not taking into account the product's energy consumption during usage as it is customers' problem.
- Reducing the amount of materials at the manufacture stage is a significant element of products' design. However, where that material comes from and ends up in at the end-of-life of products does not play an important part of material selection. Thus, respondents are not actively looking to source

materials where possible that are environmentally friendly. So, there is a lack of consideration of the whole life cycle of materials.

- No proper and convincing attention is given to material recovery and recycling by our respondents.
- Respondents are not incorporating in full, the principles of design for disassembly (DFD) into their design programmes and that could be another contributing factor to apply the WEEE directive when it comes to materials recovery and recycling.
- Respondents do major on producing user-friendly documentation, which guide users and help to implement the WEEE directive [reuse], which in turn extends the service life of their products. However, replacing old parts with new improved ones or making parts available for longer periods is not a normal practice by respondents. Thus, the principles of extending the service life of products have not been incorporated into respondents' design and/or policy.
- Our respondents may be considering energy usage as an overhead, which cannot be improved or reduced. Serious attention is not given to improve the management of energy consumption, and there is no real indication that respondents are looking at buying energy from renewable resources.
- All of our respondents are interested and aiming at achieving level one in their Eco-Design programmes which is incremental improvement of products.
- Interestingly, there is attention aimed to complete redesign of existing product concepts and alternative fulfilment of functionality and new concepts. Our respondents confirm that they are beginners and have not started.
- The majority of our respondents are still in the early stages of their Eco-Design programmes, which at that level, normally looks at incremental improvement of their exiting designs by adding the environment as one of many design attributes.
- The ultimate objective of any effective Eco-Design programme is to design and produce products that completely fit into sustainable society. Our respondents still have not reach that stage yet.

- Respondents are making some progress towards designing for disassembly, which is a prerequisite to any successful Eco-Design programme.

The following points can be made about the PDCA framework:

1. PDCA framework for Eco-Design is an approach for Eco-Design activities implementation and integration into Business's operation and strategy.
2. It is not the intention of this framework to teach business on the pure specifics of products' design, but rather on what Eco-Design principles and rules should be observed and utilised during the engineering design process and its related activities including how to integrate WEEE directive in the normal business's operation and strategy.
3. It is a generic framework that could be utilised by different types of businesses who are involved in both design and manufacture of products.
4. It generates top management commitment and greatly reduces uncertainty about the future of the Eco-Design programme.
5. It increases communication and the exchange of thoughts and knowledge among different company's departments.
6. It gets more people involved in the programme such as accountants, technicians, sales people who otherwise do not get involved. So, it involves almost all company departments in the implementation efforts.
7. Its implementation plan provides at every stage of the PDCA cycle a checklist of important questions, in order to make sure of successful execution of the plan.
8. It provides a roadmap for interested companies to successfully kick-start their Eco-Design programme, improve an existing one by helping them to produce environmentally friendly products and integrate WEEE directive in the business operation and strategy, thus guaranteeing a fair chance of success.
9. It makes the company more proactive rather than reactive to changing environmental requirement and regulations.
10. It encourages and facilitates the implementation of WEEE and RoHS directives by providing an adequate framework methodology.

11. It helps identifying strengths and weaknesses of the organisation.
12. It is validated to be a very good educational tool, which it could be used to inform businesses about the important ingredients of Eco-Design activities and to fulfil its aims and objectives.

6.2 Aim and objectives revisited

The aim of this thesis was to develop a framework for business, which would help in designing and producing environmentally friendly products by implementing Eco-Design activities and integrate the WEEE and RoHS directives into the business's operation and strategy. It is generic and incorporates the most critical factors and activities that affect the implementation and integration of Eco-Design programmes and it could be utilised by any different types of business who are involved in design and manufacture. The results indicate that the framework helps companies and businesses in their quest for Eco-Design implementation and integrate the WEEE and RoHS directives, thus it fulfils its aim and objectives.

The framework is validated to be a very good educational tool, which it could be used to inform businesses about the important ingredients of Eco-Design activities and help to integrate the WEEE and RoHS directives. The model identifies the importance of top management commitment and involvement, and the participation of all affected stakeholders in the efforts of the Eco-Design implementation and integration in the business's operation and strategy.

6.3 Recommendation for further research

The research into Eco-Design and WEEE implementation is still in it is infancy and early stages especially when it comes to making Eco-Design the defaulted way of designing and producing products. Consequently, producing viable eco-products is still in its early stages and struggling to get market acceptance as nearly 90% of all eco-technically good products will not be a success on the market for various reasons. The research in this field is still very limited and in need of contributions from both the world of academia and industry. It is believed that this thesis is a much needed academic contribution towards finding ways to help companies implementing and integrating Eco-Design activities into their operation and strategy, thus producing environmentally friendly and economically viable product that would make successfully into the marketplace.

The following recommendations are made:

- Pilot the proposed framework in a product industry, and focus on electrical and electronic industries to implement WEEE and RoHS Directives.
- Encourage the EEE companies when applying the directives by incentives and rewards.
- The help and advice they could get from the government.
- Extend the empirical research to cover experience from other countries.
- Design an award for best practice in Eco-design similar to Baldrige Awards, which are based on enablers and results.

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APPENDIX A: QUESTIONNAIRE

I. Information about the organisation and responsibility

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1. How many employees does your organisation employ? (Please tick one only)

a) Less than 50 O
b) 51 to 100 O
c) 101 to 200 O
d) 201 to 500 O
e) More than 500 O

2. Is your organisation part of a group of companies?
a) Yes O
b) No O

If yes, please specify partner(s) nationality? (Please tick all that apply)

a) UK O
b) EU other than UK O
c) Japan O
d) USA O
e) Not Applicable O
f) Other (Please specify) ___________

3. What is your job title in your organisation? (Please tick one only)

a) Owner or senior director O
b) Design manager O
c) QFD facilitator O
d) Manufacturing manager O
e) Production Manager O
f) Other (Please specify) ___________

4. What is your job focused on? (Please tick all that apply)

a) Environment O
b) Design O
c) Manufacturing O
d) Production O
e) Recycling and/ or reuse O
f) Other (Please specify) ___________
g) All or most of the above O

5. In your organisation what is the type of your product? (Please tick all that apply)

a) Manufacture and sell EEE and your own brand name. O
b) Resell (under your own brand name). O
c) Export or import EEE into the EU. O

d) Other (please specify) ______________________

II. Information about the Waste of Electrical and Electronic Equipment (WEEE) and the Restriction of Hazardous Substances (RoHS) Directives

6. Is the products or end application in your organisation covered by the WEEE and RoHS Directives? (Please tick one only)

a) Yes O b) No O
c) Do not know O

7. Is the products or end use of components/ subassemblies in your organisation fall under one of the following applications and not rated greater than 1000V ac or 1500dc? (Please tick all that apply)

a) Large and small household appliances O
b) IT equipment and Telecommunication O
c) Consumer equipment O
d) Electrical and electronic tools O
e) Toys, leisure and sports equipment O
f) Others ____

8. Do the products in your organisation contain, or potentially contain the following materials (not exempted under the RoHS Annex)? (Please tick all that apply)

a) Lead O
b) Mercury O
c) Hexavalent chromium O
d) Cadmium O
e) PCBs O
f) Polybrominated biphenyls (PBB) O
g) Polybrominated biphenyl ether (PBBE) O
h) Radioactive substances O
i) Asbestos O
j) Plastic parts weigh more than 25 grams O

9. If the products in your organisation fall into the class of separately collected, does the product contain any of the following listed in Annex II of the WEEE, which will be required to be removed from the products at end-of-life for separate treatment. (Please tick that all apply)

a) Fluids O
b) Polychlorinated biphenyls (PCB) containing capacitors O
c) Mercury containing components, such as switches O
d) Batteries O
e) Printed circuit boards of mobile phones O
f) Other than PCB greater than 10 cm^2 O
g) Toner cartridges, liquid and pasty O
h) Plastic containing brominates flame-retardants O
i) (CFC), (HCFC), (HFC) and (HC) O

j) Gasdischargelamps O
k) Liquid crystal displays of a surface greater than 100cm² O
l) External electric cables O
m) Components containing refractory ceramic fibres O
n) Components containing radioactive substances O
o) Asbestos waste O
p) Cathode ray tubes O
q) Other (please specify) ____________________

III. Preparing for the WEEE

10. Does your organisation (producers) provide re-use and treatment information?

a) Yes O b) No O

If yes, on which way the information is provided?

a) Manual O b) CD-Rom O c) On line O
d) Other (please specify) _____________________

11. What actions does your organisation to meet the WEEE Directive? (Please tick that all apply)

a) Register O
b) Meet information requirements O
c) Provide financial guarantees O
d) Meet design requirements O
e) Finance the collection, treatment, recovery and Disposal of WEEE O
f) Take more proactive approach to sustainable design (eco-design) O
g) Others (please specify)___________________________________

Do not Know	Not at all	A limited extent (Less than 25%)	Moderate extent (25% to 50%)	A great extent (51% to 75%)	Avery great extent (More than 76%)
0	1	2	3	4	5

IV. Tools for Eco-design

12. The following are the most popular ***tools for environmental analysis and instruction.*** Please rate the extent your organisation employ them. (Please tick appropriate answer)

a)	LCA (Life Cycle Assessment)	0 1 2 3 4 5
b)	MIPS Analysis (Material Input Per Service Unit)	0 1 2 3 4 5
c)	CED Analysis (Cumulative Energy Demand)	0 1 2 3 4 5
d)	MET Matrix (Material, Energy& Toxicity)	0 1 2 3 4 5
e)	Eco-Compass	0 1 2 3 4 5
f)	Checklists	0 1 2 3 4 5
g)	ABC- Analysis	0 1 2 3 4 5
h)	Eco-Estimator	0 1 2 3 4 5
i)	Eco-Checklist	0 1 2 3 4 5
j)	WEEE directive	0 1 2 3 4 5
k)	Check list for recyclable fittings and joint engineering	0 1 2 3 4 5
l)	Other (please specify)_________________________	

13. The following are the most popular ***tools for Creativity Techniques***. Please rate the extent your organisation employ them. (Please tick appropriate answer)

a) Classical Brainstorming	0 1 2 3 4 5
b) Brain writing	0 1 2 3 4 5
c) Bionics (Coping from nature)	0 1 2 3 4 5
d) Heuristics Principles	0 1 2 3 4 5
e) The Morphological Box	0 1 2 3 4 5
f) Progressive abstraction	0 1 2 3 4 5
g) TRIZ (Theory of Inventive problem solving)	0 1 2 3 4 5
h) Other (Please specify) _____________________	

14. The following are the most popular ***tools for setting priority and Decision Making***. Please rate the extent your organisation employ them. (Please tick appropriate answer)

a)	Checklist for Selecting New Solution	0 1 2 3 4 5
b)	Eco-design Matrix	0 1 2 3 4 5
c)	Eco-design Portfolio	0 1 2 3 4 5
d)	Quality Profile (Pragmatic Differential)	0 1 2 3 4 5
e)	Dominance Matrix of Paired Comparison	0 1 2 3 4 5
f)	HoEQ (House of Environmental Quality)	0 1 2 3 4 5
g)	Other (please specify) ________________	

Do not Know	Not at all	A limited extent (Less than 25%)	Moderate extent (25% to 50%)	A great extent (51% to 75%)	Avery great extent (More than 76%)
0	1	2	3	4	5

15. The following are the most popular ***tools for Cost Accounting***. Please rate the extent your organisation employ them. (Please tick appropriate answer)

a) Benefit Analysis 0 1 2 3 4 5
b) TCA (Total Cost Accounting) 0 1 2 3 4 5
c) LCC (Life Cycle Costing) 0 1 2 3 4 5
d) FCA (Full Cost Accounting) 0 1 2 3 4 5
e) Cost Accounting and Eco-design 0 1 2 3 4 5
f) Other (Please specify) ________________

V. Eco-design external information sources

16. Please rate the importance of the following information for your organisation. (Please circle or tick appropriate answer)

a) Publications, journals, handbooks and books 0 1 2 3 4 5
b) Contact with relevant authorities 0 1 2 3 4 5
c) Visiting workshops/ seminars/ meetings 0 1 2 3 4 5
d) Contact with industry group 0 1 2 3 4 5
e) Advice from consultant or insurance companies 0 1 2 3 4 5
f) TV, radio and newspaper 0 1 2 3 4 5
g) Internet 0 1 2 3 4 5
h) Government, Industry, business publications 0 1 2 3 4 5
i) University publications 0 1 2 3 4 5
j) Other (Please specify) ___________________

VI. Design considerations

For each lifecycle stage consider appropriate design objectives or attributes, and whether these have been met or adequately considered.

The first consider: Environmental concerns

17. In your organisation are the environmental aspects/impacts or design judged to be significant by virtue of those? (Please tick all that apply)

a) Regulatory requirements (WEEE/RoHS) 0 1 2 3 4 5
b) Customer requirements 0 1 2 3 4 5
c) Environmental load 0 1 2 3 4 5
d) Other (please specify)_______________

Do not Know	Not at all	A limited extent (Less than 25%)	Moderate extent (25% to 50%)	A great extent (51% to 75%)	Avery great extent (More than 76%)
0	1	2	3	4	5

The second consider: System Design

18. In your organisation has the design been considered? (Please tick all that apply)

a) Reduced complexity of enclosures and assemblies 0 1 2 3 4 5
b) Fewer parts 0 1 2 3 4 5
c) Multifunctional parts e.g. Single fastener 0 1 2 3 4 5
d) Using common parts in different designs 0 1 2 3 4 5
e) Multifunctional products 0 1 2 3 4 5
f) Is longevity feasible 0 1 2 3 4 5
g) Is source reduction considered 0 1 2 3 4 5
h) Others (please specify) ________________________

The third consider: Material sourcing

19. In your organisation are recycled materials specified where possible? (Please tick that all apply)

a) For product materials 0 1 2 3 4 5
b) For packaging 0 1 2 3 4 5

20. In your organisation have the Hazardous materials been… (Please tick one)

a) Avoided 0 1 2 3 4 5
b) Minimised 0 1 2 3 4 5

21. In your organisation have the scarce resources been… (Please tick one)

a) Avoided 0 1 2 3 4 5
b) Minimised 0 1 2 3 4 5

The fourth consider: Manufacturing and Distribution

22. What is the component/assembly in your organisation designed and manufactured for? (Please tick that all apply)

a) Energy conservation in manufacture 0 1 2 3 4 5
b) Energy conservation in distribution logistics 0 1 2 3 4 5
c) Waste Minimisation in manufacture 0 1 2 3 4 5
d) Minimise the air and water pollution 0 1 2 3 4 5
e) Minimise the water and material use 0 1 2 3 4 5
f) Other (please specify)_____________

Do not Know	Not at all	A limited extent (Less than 25%)	Moderate extent (25% to 50%)	A great extent (51% to 75%)	Avery great extent (More than 76%)
0	1	2	3	4	5

The fifth consider: Use

23. In your organisation what is the product designed for? (Please tick that all apply)

a) Minimum power consumption in use 0 1 2 3 4 5
b) Minimum packaging 0 1 2 3 4 5
c) Minimum consumable use 0 1 2 3 4 5
d) Minimum waste consumables in use (e.g. Batteries) 0 1 2 3 4 5
e) Serviceability, longevity and durability 0 1 2 3 4 5
f) Others (please specify) ______________________

The sixth consider: End-Of-Life

24. Has the design for disassembly and component recovery been considered in your organisation? (Please tick that all apply)

a) Design for non-destructive removal 0 1 2 3 4 5
b) Design for speedy diagnosis and refurbishment 0 1 2 3 4 5
c) Design for close loop manufacturing 0 1 2 3 4 5
d) Design for use in secondary applications 0 1 2 3 4 5

25. In your organisation is the material recovery feasible or required (For list of what will have to be removed under the WEEE directive)? (Please tick that all apply)

a) Is there a market for the material 0 1 2 3 4 5
b) Is there a separation and recycling technology and infrastructure 0 1 2 3 4 5
c) Is there any other requirement for material separation? (e.g. removal of hazardous materials before disposal) 0 1 2 3 4 5

26. Materials: Have the following been specified/ achieved in your organisation? (Please tick that all apply)

a) Material combinations compatible for recycling 0 1 2 3 4 5
b) Use of recyclable materials 0 1 2 3 4 5
c) Grouping hazardous or non recyclable components 0 1 2 3 4 5
d) Use of standard screw heads 0 1 2 3 4 5
e) Use of detachable leads and push in plugs 0 1 2 3 4 5
f) Other (please specified)______________________

Do not Know	Not at all	A limited extent (Less than 25%)	Moderate extent (25% to 50%)	A great extent (51% to 75%)	Avery great extent (More than 76%)
0	1	2	3	4	5

27. Assembly/disassembly methods: Have the following been specified/ achieved in your organisation? (Please tick that all apply)

a) Is the component/assembly designed to ease of assembly and for separability 0 1 2 3 4 5
b) Simple component mechanism and orientation 0 1 2 3 4 5
c) Provision of grasping parts 0 1 2 3 4 5
d) Use of screws in preference to rivets 0 1 2 3 4 5
e) 'Snap fit' or spring clips in preference to threaded fasteners where possible 0 1 2 3 4 5
f) Common fasteners 0 1 2 3 4 5
g) Other (please specify) ______________________

VII. Design For X (DFX)

28. The following are the Design for X Family (DFX); to what extent does your organisation utilize these when it comes to designing environmentally products. (Please tick appropriate answer)

a) Design for assembly (DFA) 0 1 2 3 4 5
b) Design for disassembly (DFD) 0 1 2 3 4 5
c) Design for manufacture (DFM) 0 1 2 3 4 5
d) Design for quality (DFQ) 0 1 2 3 4 5
e) Design for recycling (DFR) 0 1 2 3 4 5
f) Design for serviceability (DFS) 0 1 2 3 4 5
g) Design for testability (DFT) 0 1 2 3 4 5
h) Design for up-grade (DFUG) 0 1 2 3 4 5
i) Other (Please specify) ___________________

VIII. Management system

29. Does your organisation have certification or validation (related to Eco-design, WEEE and Quality)? (Please tick that all apply)

a) ISO 9000 O
b) ISO 14000 O
c) ISO 14001 O
d) ISO 14004 O
e) ISO 14040 O
f) ISO 14020 O
g) Other (Please specify) ____________________

Do not Know	Not at all	A limited extent (Less than 25%)	Moderate extent (25% to 50%)	A great extent (51% to 75%)	Avery great extent (More than 76%)
0	1	2	3	4	5

30. Does your organisation plans to achieve any certification or validation related to eco-design or WEEE in the next two years? (Please tick one only)

a) Yes O b) No O c) Don'tknow O

37. Which of the following reasons do you or your organisation consider important when implementing management standards? (Please tick appropriate answer)

a)	Facilitating compliance with eco-design legislation	0 1 2 3 4 5
b)	Facilitating compliance with WEEE and RoHS directives	0 1 2 3 4 5
c)	Required by customer	0 1 2 3 4 5
d)	Competitive advantage	0 1 2 3 4 5
e)	Trade and International Trade	0 1 2 3 4 5
f)	Overseas parent company	0 1 2 3 4 5
g)	Eliminate non-conformance results	0 1 2 3 4 5
h)	Improve eco-design Performance	0 1 2 3 4 5
i)	Other (Please specify) ______________________	

IX. Environmental Legislation Issues

31. To what extent does your organisation face the following problems? (Please tick appropriate answer)

a)	Compliance with regulations (WEEE and RoHS)	0 1 2 3 4 5
b)	Communication and implementation of these regulations in organisation	0 1 2 3 4 5
c)	Insufficiency of Eco-design legislation and regulations	0 1 2 3 4 5
d)	Interference and conflict between authorities	0 1 2 3 4 5
e)	Recognition of importance of Eco-design with in organisation	0 1 2 3 4 5
f)	Leadership attention/responsibilities	0 1 2 3 4 5
g)	Insufficient data resources	0 1 2 3 4 5
h)	Other (Please specify) ________________________________	

32. Please rate the importance of the following suggestions regarding additional help you might or wish to receive from the Authorities (Please tick appropriate answer)

a)	Clear simpler regulations	0 1 2 3 4 5
b)	Aim-target regulation rather than detailed legislation	0 1 2 3 4 5
c)	Adoption of international legislation and guides	0 1 2 3 4 5
d)	Providing more education/ information and training	0 1 2 3 4 5
e)	Establishing national database	0 1 2 3 4 5
f)	Establishing national guide for managing Eco-design	0 1 2 3 4 5
g)	Other (Please specify) _________________________	

APPENDIX B: COVERING LETTER

The augmentation of Eco-design to include WEEE and RoHS

Development of a framework for the implementation of eco-design(Design for Environment)Principles that helps to take into account the adaptation of the waste of electrical and electronic equipment directive (WEEE),and the restriction of hazardous materials (RoHS)use in electrical and electronic equipment.

Dear Sir or Madam

I am reading for an MPhil Degree at the School of Engineering Design and technology at the University of Bradford under the supervision of Both Prof. Abd-Alhameed and Dr Tizaoui.

The initial objectives of the research are as follows:

- Establishing a wide view about the state of Eco-design activities in a sample of companies in UK, by analysing the data gathered using special software.
- Establishing a wide view about the state of WEEE and RoHS directives in a sample of companies in UK, by analysing the data gathered using special software.
- Identifying the strengths and weaknesses in existing Eco-design programmes that have been investigated.
- Identifying the improvement in Eco-design in order to take into account the adaption of WEEE &RoHS directives.
- Developing a framework to help UK industry to augment (enlarge-increase) Eco-design to include WEEE &RoHS successfully.
- Finally helping the participated companies such as your company in the Eco-design, WEEE &RoHS fields by sharing the outcome of the research.

Prof. Abd-Alhameed, Dr Tizaoui and I would be most grateful if you or the person responsible for the Eco-design programme or WEEE directive could complete the attached questionnaire and return it as soon as possible.

We know the completion of the questionnaire is an imposition on your time but there will be real benefits from this research, and we will provide you with the detailed analysis results to give to you an idea and to improve your Eco-design, WEEE &RoHS Programme.

Could you please answer all the questions, although the latter may not cover all aspects and activities of Eco-design, WEEE &RoHS.

We assure you that all information collected will be treated in the strictest confidence, and will be used only for the purposes of this academic research. No organisation, party or individual will be named in any ensuing publication and the information will be collected and classified without reference to the name of the respondent(s) or their organisation(s).

Please do not hesitate to contact me if you require any clarification or information and allow me to thank you in advance for your time and support.

Yours truly,

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APPENDIX C: KEYWORDS INFORMATION'S SHEETS

Eco-design (Ecological Design) or Design for Environment (DFE):

Several methods and tools have already been developed which can help to reach the goal of a more sustainable economy.

WEEE Directive:

Waste of electrical and electronic equipment directive.

RoHS Directive:

The restriction on hazardous substances used in the electrical and electronic equipments directive.

LCA (Life Cycle Assessment):

Tool to identify and assess the potential environmental impacts associated with a product throughout its complete life cycle.

MIPS Analysis (MIPS=Material input per service unit):

Tool to identify and assess the environmental impacts connected to a product, process, or material throughout its life cycle taking account of energy and materials inputs.

CED Analysis (Cumulative Energy Demand):

Tool to identify and assess a product's environmental impacts across its life cycle on the basis of its energy input and content.

Quality Function Deployment (QFD):

Quality function deployment is asset of a powerful product development tools that were developed in Japan to transfer the concepts of quality control from manufacturing process into new product development process.

Environmental Effect Analysis (EFA):

The method's origin is the quality method Failure Mode Effect Analysis (FMEA). The objectives of an EFA are to identify and evaluate and significant environmental impacts of a product in an early stage of a development project.

Total Cost Accounting (TCA):

TCA aims at revealing costs that are difficult to pinpoint or are hidden including liability costs.

Life Cycle Costing (LCC):

LCC includes consideration of impacts of a product beyond the production phase, and takes into account the cost factors such as labour and materials.

Full Cost Accounting (FCA):

FCA adds a further dimension to LCC by taking account of the effects of a product has on specific stakeholders and costs this entails for them.

FCA=LCC+ TCA