

# An Empirical Study of how Innovation and the Environment are Considered in Current Engineering Design Practise

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## Abstract

This paper reports the findings of a study of the current innovation and environmental considerations of six businesses that design and manufacture products affected by the product-related environmental legislation. Activities undertaken with the businesses provide insights into their New Product Development (NPD) processes, their innovation capabilities and their actions to improve their environmental performance. Several features of their NPD processes are suggested as presenting opportunities for eco-design tools to be integrated into design practises without negatively affecting the current NPD process. Finally, a conceptual framework is proposed which highlights the inter-relations between business, environmental, and customer requirements of a product across its lifecycle.

**Keywords:** Eco-design; New Product Development; Design tools

## 1 INTRODUCTION

It has been widely noted that although a wide range of eco-design tools have been developed relatively few of them have been adopted into industrial practices [1]. One response from researchers has been to propose modified NPD models which emphasise the integration of eco-design tools into the process [2] [3]. However, it has been noted that in practice, of the relatively few businesses who have adapted their NPD

process to improve product environmental performance, most have ignored the models proposed by academic researchers and have instead developed their own models based on real-life practice [4].

This research takes the alternative approach in which the aim is to modify existing eco-design tools or develop new ones such that they fit into the existing NPD process of the business [5]. This paper reports on a study of the innovation and environmental practises of six businesses in the South-West of England. The results of this study along with the subsequent analysis contribute towards the completion of tasks 1 and 2 of the wider research program, as shown in Figure 1.

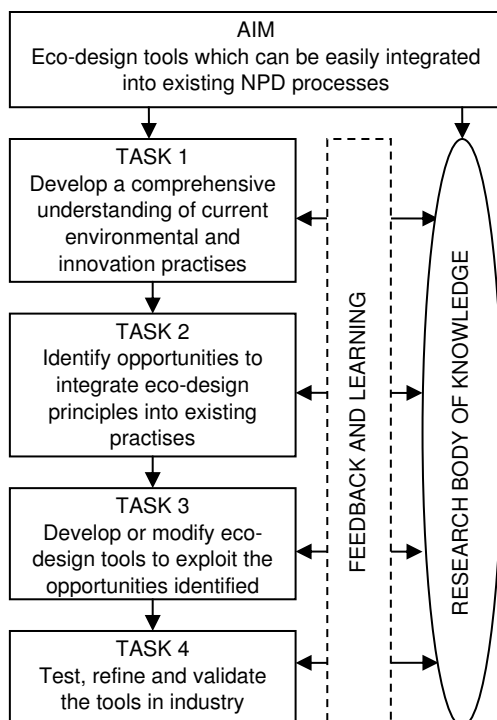


Figure 1: Research aims

## 2 METHODOLOGY

### 2.1 Selection and recruitment of businesses

The study was conducted with six businesses that design and manufacture products in the South-West of England with product ranges that are likely to be affected by the Waste Electrical and Electronic Equipment (WEEE) [6]. Restriction of

Business	Size	Product Range
A	Medium	Professional audio equipment
B	Medium-Large	Location/inspection equipment, sensors
C	Medium	Water/central heating controls, utilities metering
D	Medium	Heating, ventilation and hot water systems
E	Medium	Vending machines
F	Small	Industrial testing equipment

Table 1. Characteristics of the businesses surveyed

Hazardous Substances (RoHS) [7], or Energy Using Products (EuP) Directives [8]. Whilst primarily a study of design activities, there was interest in selecting businesses who also manufacture in the area as this would lead to greater engagement with the manufacturing process and so greater knowledge of the environmental impacts of the product. The research literature has suggested that product-related environmental legislation is a strong driver for eco-design [9] and hence by selecting businesses affected by such legislation it was hoped that further insight could be gained into the validity of this idea. Business characteristics are summarised in Table 1

## 2.2 Development of research methods

The aim of the research was to gain an understanding of the **real** practises of businesses. It was therefore decided to develop a range of activities which would require the business to demonstrate their environmental and innovation performance and capabilities by providing evidence and concrete examples.

The visits lasted around three hours and the participants generally included, as a minimum, the Environmental Manager (or equivalent) and the Design/Technical Manager. A typical visit programme is shown below with subsequent sections providing details of the key activities.

### *Visit programme*

- Presentation by the researchers on the latest developments in the WEEE, RoHS and EuP Directives followed by discussions on how they affect the business
- Activity to assess the level of environmental 'pro-activity' of the business within its supply chain
- 'Life cycle Thinking' activity to assess current environmental actions throughout the product life cycle
- Factory tour
- New Product Development (NPD) process mapping activity
- Innovation benchmarking questions
- Recording of the business's current 'innovation funnel'

### *Life cycle thinking activity*

A chart listing the seven lifecycle phases was presented to the participants who were given a brief explanation of the principles of life cycle thinking. The researcher then went through each lifecycle phase asking for examples of where actions or initiatives had been taken by the business to reduce the environmental impacts associated with that phase, prompting where necessary.

### *NPD process mapping*

This activity was introduced by presenting the participants with examples of both formal and less formal NPD process models and asking which of the examples most closely related to the businesses' own processes. The participants were then asked to talk through and map out their own NPD process on a flipchart. This was map was further elaborated by asking the participants to add comments to identify general strengths, in green pen, and general weaknesses, in red pen.

### *Innovation benchmarking questions*

An abridged version of the UK DTI's 'Living Innovation' [10] benchmarking questionnaire was used. Three sets of three

questions covered the businesses' ability to 'Inspire' their designers, 'Connect' with their customers and suppliers, and successfully 'Create' – take good ideas into manufacture. Each question was written on a separate small card with a 4 point Likert-type scale at the bottom where one participant noted the consensus of the group by ticking the appropriate box. This consensus-seeking method was intended to obtain a response which was as representative of 'the business' as possible.

## 3 RESULTS

In order to facilitate inter-business comparison and benchmarking, a quantitative scoring system was developed for some of the activities. The scoring system for the activities and the business results are presented here:

### *Supply-chain pressures activity*

Businesses who applied more environmental pressures on their suppliers than they received from their customers were deemed to be environmentally 'pro-active' in their supply chain, and vice-versa. Businesses were awarded 0 to 4 points for this activity depending on their level of 'pro-activity' with a score of 2 indicating a neutral balance. Only one business was considered to be 'pro-active' on environmental issues according to the criteria, half of the businesses were found to be 'reactive', and the remainder were 'neutral'.

### *Life cycle thinking activity*

Table 2 shows the number of businesses who have made 'significant' efforts in each of the life cycle phases. A 'significant' effort point was awarded if a business was able to provide three or more examples of initiatives or methods they use to which would also reduce the environmental impacts during that particular phase. Two-thirds of the businesses were able to demonstrate significant effort in three of the lifecycle phases with the remaining businesses able to demonstrate significant effort in at least one phase.

Life cycle phase	Companies making a 'significant effort'
New concepts	2
Selection and use of materials	1
Production optimisation	5
Distribution system	3
Impacts during use	1
End-of-life strategy	3

Table 2: Results of life cycle thinking activity

### *Innovation benchmarking questions*

The innovation benchmarking questions were scored by awarding +2 points for a 'strongly agree' response, +1 for an 'agree' response, and conversely -1 and -2 points were awarded for 'disagree' and 'strongly disagree' responses respectively. All businesses scored positively on the benchmarks but the scores varied considerably from +4 to +12 points. In all cases the scores appeared to be consistent with the researchers' views as to the relative innovation 'strength' of the businesses.

## 4 DISCUSSION

### 4.1 Environmental performance of businesses

#### *Supply-chain pressures activity*

Several of the companies commented that there had been an increase in the dialogue between the business and their supply-chain in recent years. In most cases this dialogue appeared to be limited to issues directly relating to compliance with legislation such as the WEEE and RoHS Directives. However in some cases customers were now requesting information on wider issues such as if the business had an environmental management system. Whilst most businesses had responded to requests for information from customers, it did not appear that they had made efforts to improve the environmental performance of their products beyond the minimum standards required for legislative compliance.

#### *Life cycle thinking activity*

From Table 2 it is noteworthy that five of the manufacturers have made significant efforts to reduce environmental impacts through 'production optimisation'. This is logical given that improvements made to the production phase are likely to lead to direct cost-savings for the manufacturer i.e. through reduced energy costs or waste minimisation. The wide-spread interest in 'cleaner production' during the 1990s is another likely explanation of the success seen in this area.

In contrast, just one manufacturer had made significant improvements to the 'impacts during use' of their products. Businesses A, D and E manufacture products clearly have very significant impacts during their use phase and yet only one had made significant improvements in this area. The question therefore presents itself as to why the other two manufacturers had not yet attempted to make improvements in the use phase of their products' lifecycle? In both cases the businesses estimated the use phase as being the posing the greatest environmental burden, therefore lack of awareness is ruled out. In fact both businesses explained that energy efficiency was not an important consideration for their customers, which was reflected in their product specification and weightings.

Whilst undertaking the life cycle thinking activity with businesses it was noted that they were often unable to recognise the benefits that their 'cost-saving' activities were

having on the environment (i.e. reducing material usage) without significant prompting from the researchers. It is suggested that this is because these activities had originally been framed as 'cost-saving' activities and the participants struggled to view these activities through an 'environmental frame'.

Several businesses commented that they were pleasantly surprised by the number of positive environmental actions that were attributed to the business within the life cycle thinking activity. Furthermore, four out of the five businesses who completed feedback forms following the visit agreed or strongly agreed that due to the visit they planned to improve their environmental actions. This implies that the activity had gone some way towards 'establishing a new mindset in which the importance of the environmental issues is established' – an important factor for the success of eco-design activities according to the literature [16].

### 4.2 Innovation capabilities of businesses

#### *NPD process mapping*

The NPD models were analysed with a view to identifying popular tools or methods; and similarities or features of the process which might provide suitable 'entry-points' for eco-design. The results of this analysis are presented in Table 3.

One weakness which was mentioned by the majority of the businesses concerned the difficulty in developing an accurate and stable requirements specification. Many businesses mentioned that work progressed even when the requirements specification had not been formally agreed or that changes to the specification were often made even after it had been agreed. This was perceived as wasting engineering effort and slowing project progress. Research literature suggests that the formulation of the requirements specification is a key stage for the integration of environmental considerations [17]. This suggests that there are opportunities for methods which can both improve the requirements specification formulation process and integrate environmental considerations.

#### *Innovation funnel*

It was observed that businesses found it difficult to discuss 'failed' projects and struggled to provide examples of failed projects. Academic literature [18] suggests that successful innovators have a high number of projects drop out of the NPD process but that these failures are mitigated by failing

Common 'Strengths'	Business benefit	Eco-design opportunity
Use of QFD	Ensure that requirements specification accurately represents needs of customer	Promote use of QFD for the Environment [11] which extends existing QFD tools by including the 'voice of the Environment' to set environmental targets
Regular safety and compliance reviews	Avoid the negative cost, time and brand image implications of producing non-compliant or unsafe products	Include an environmental review as part of the safety review – cover both environmental compliance and ensure environmental targets will be met [12]
Strong emphasis on cost-management and designing to a price point	Ensure that product is price competitive within its market segment	Use of financial methods such as environmental accounting [13], or Eco-Value [14] to emphasise cost benefits to business and customer of eco-design
Customer feedback as an input to the design process	Ensure that customer requirements are understood	Enhance customer focus by moving from 'eco-efficient' satisfaction of <i>requirements</i> to the effective fulfilment of <i>needs</i> through 'co-development' methods [15]

Table 3: Opportunities for eco-design within existing NPD process models

'early' i.e. before significant time and resources have been committed to the project. Several businesses commented that they made efforts to learn from their failed projects, but overall it was concluded that the 'fail early and often' culture was not present in any of the businesses studied.

A number of differences were noted between the innovation tunnels of the businesses in terms of the number of new projects launched per year, the time taken in development etc. However, no further generalisations can be drawn from these results as it is likely that the variations observed are as much due to contextual factors (such as the technology cycle of the industry, the size of the business, the legislative environment) as they are to the innovation strategy or culture of the business.

### 4.3 Development of a conceptual frame work

It was noted in section 4.1 that the businesses studied in this project struggled to recognise the environmental benefits often associated with their cost-driven actions. It was also noted that many of the businesses placed significant emphasis on trying to capture and understand the customer's requirements within the NPD process as is reflected in the structure of their NPD processes and the common use of tools such as QFD. Based on these two observations it was suggested that a conceptual framework which clarifies the inter-relationships between the business, environmental, and customer requirements of a product would be useful. In the following section a conceptual framework which links the requirements of a product across its life cycle from the perspectives of the business, the environment and the customer is presented, its relevance to previous work is discussed, and finally applications of the framework are suggested.

*Previous work linking the business, environmental, and customer aspects of product development*

Although by no means a comprehensive review, there follows a summary of how the BEC Synergies diagram relates to similar frameworks presented in the research literature.

In discussing the links between business, customers, and the environment a key theme which emerges from the literature is the problem of how to motivate a business to consider the environmental aspects of product development (it is assumed here that businesses are already motivated to meet customer product requirements). Given that businesses are essentially economically driven, one logical approach which has received much attention is to emphasise the link between environmental and economic performance. For example, the World Business Council for Sustainable Development make through what they term 'eco-efficiency'. They state that eco-efficiency say is achieved, '...by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity' [19].

In adopting this philosophy, the logical question for a business to ask is 'when does it pay to be green?'. Reviewers have commented that several attempts have been made to answer this question [20] with varying and sometimes conflicting responses. However, other authors have suggested that trying to prove or disprove this link has led to a polarising of the debate and that rather the question should instead be 'when does it make sense to be green?' [20]. What is clear is that there are a range of tools available which attempt to quantify the links between environmental and economic performance e.g. [13].

Another major focus of research has been in understanding the stakeholders within the environmental NPD process, including their roles, and interactions. A stakeholder map has been proposed [21] which categorises stakeholders in terms of their ability to influence products characteristics. The model distinguishes three levels of stakeholder with the most

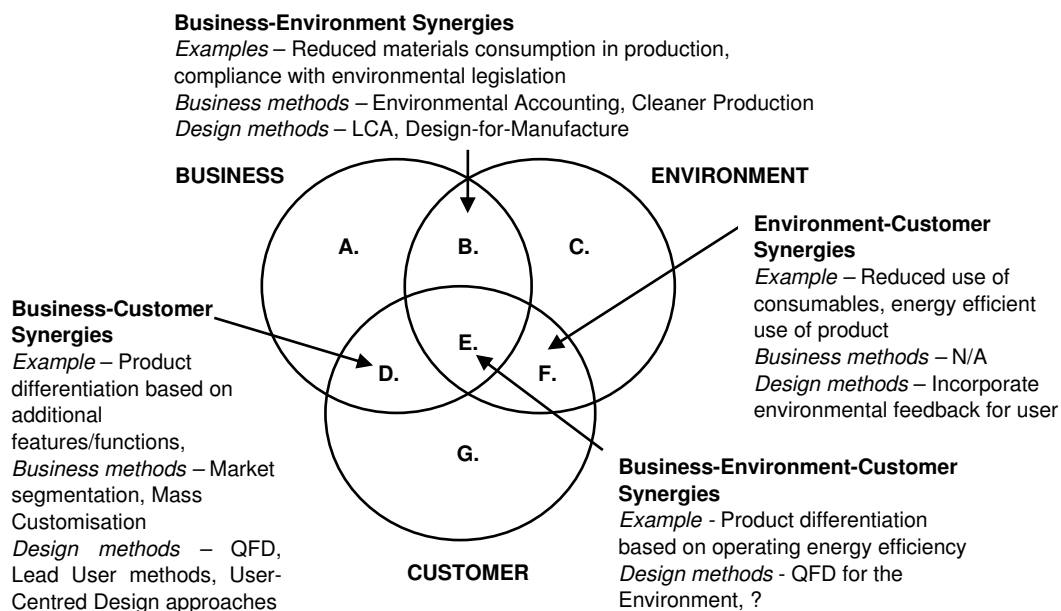


Figure 2: The inter-relations between business, environmental and customer requirements across the product life cycle

influential being the 'Design Team', followed by the 'Product Chain' and the 'External Stakeholders'. Other work [22] has extended the existing Customer Value Chain Analysis tool to include environmental considerations. The major stakeholders are listed and the links between these parties are drawn using a notation system to distinguish between the three types of flow: money, stuff (machines, materials, information etc), and issues (complaints, regulatory influences etc). This method allows the business to ascertain who the key project customers are, and by further analysing the flow of money, stuff and issues between these key parties, the 'Voice Of the Customer' (VOC) can be generated.

The final research focus has been on how to generate a list of product requirements to represent the views and interests of the key stakeholders. A work pack produced by the US Environmental Protection Agency [23] encourages the business to consider the product in terms of legal, cultural, cost, performance and environmental requirements. A separate matrix is populated with requirements for each of these areas, with the environmental matrix using axes of product lifecycle phase against 'product', 'process' and 'distribution'.

A somewhat similar tool which focuses on purely on environmental and functional requirements is QFD for the Environment (QFDE) [11]. QFDE can assist in formulating a requirements specification by incorporating both the 'Voice of the Customer' and the 'Voice of the Environment'. The requirements of the business are considered to some extent if we assume that meeting the customer's requirements is a major requirement and benefit for the business. QFDE is particularly useful in that it quantifies the conflicts between requirements and hence it can be used when making design decisions requiring a trade-off between competing requirements.

Unfortunately, none of the tools or methods discussed here can represent the product requirements from the viewpoint of the business, the environment and the customer **simultaneously**. Recognition of this fact led to the development of the 'Business-Environment-Customer Synergies' diagram presented in the following section.

#### *The Business-Environment-Customer Synergies Diagram*

The Business-Environment-Customer (BEC) Synergies diagram shown in Figure 2. is intended to classify, and represent the inter-relations between, the key stakeholder requirements of the product throughout its lifecycle (referred to from now on as simply 'product requirements'). Product requirements are positioned on the diagram according to the stakeholders which that particular requirement will benefit. Here, the term 'synergy' has been used to describe requirements which benefit more than one stakeholder. We can further define 'dual benefits' as a product requirement which benefits two stakeholders (i.e. sections B., D., or F.), and a 'tri-benefit' as a requirement which benefits all three stakeholders (i.e. section E.). Product differentiation based on additional product features or functions is an example of a dual-benefit as it: benefits the customer who receives a product which meets additional requirements beyond the primary functional requirements; and it benefits the business who can use those additional features to distinguish their product from the range of competing products which perform the same primary function.

Beyond this classification of product requirements, the BEC Synergies diagram can be used to classify the types of business methods or design tools which may be appropriate when attempting to fulfill the requirements within a sector. For example, the identification of market segments and the use of Quality Functional Deployment may be an appropriate business method and design tool respectively for fulfilling the product differentiation requirement described previously.

#### *Discussion of the Business-Environment-Customer Synergies Diagram*

Using the BEC Synergies diagram to consider the challenges of integrating eco-design into the product development activities of a business has highlighted several issues which may merit further investigation.

First, it would seem logical to suggest that the objectives of (environmental) sustainable development are most likely to be met by products which fulfill 'tri-benefit' requirements as defined previously. It is suggested that aiming to create products which fulfill 'tri-benefit' requirements might make good strategic sense from a point of view of the business. This is perhaps best explained by considering the alternative scenarios.

A business which focuses its efforts on improving the product lifecycle with regard to customer and business requirements only (sector D) may have medium term success by ensuring positive and profitable relations with customers are maintained by providing products which successfully meet their requirements however in the long-term their failure to manage environmental risks may result in significant future costs to comply with environmental legislation or to rectify the environmental impacts of their products. Alternatively, a business which pursues environmental requirements to the extent that they neglect customer requirements (sector B) are soon likely to be overtaken and replaced by businesses creating products which better fulfill customer requirements. Finally, focusing efforts on meeting product requirements which only benefit the business (sector A), may result in short term gains in terms of cost savings, but it is likely to expose the business to both the aforementioned types of risk. For further analysis of the types of business context in which 'it makes sense to be green', and the types of strategies which may be appropriate in those cases, see [24].

Ascertaining the validity of this reasoning, and gauging the extent to which businesses are persuaded to act based on this reasoning, are major issues for future work. If, as is hoped, businesses do decide to focus their efforts on meeting tri-benefit requirements within the product lifecycle then they will need tools to assist them, both to highlight the opportunities and to implement a solution. QFDE is suggested as being one tool which does manage to incorporate requirements of the business, the environment and the customer to a certain extent, however, it does not assist businesses beyond this stage of the NPD process.

There therefore seems to be considerable scope for modifying existing tools or creating new tools which aim assist the business to fulfill tri-benefit requirements. Whilst such tools will be needed across the business functions, the focus of future work within the research program presented here will be on developing design tools which meet this aim and can be easily integrated into a businesses existing NPD process.

## 5 ACKNOWLEDGEMENTS

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